NAVAL PROFESSIONAL PAPERS
No. 17

MAGNETISM
OF
IRON AND STEEL SHIPS

BUREAU OF NAVIGATION
NAVY DEPARTMENT

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THE MAGNETISM

OF

IRON AND STEEL SHIPS:

AN EXPLANATION OF THE VARIOUS WAYS IN WHICH IT AFFECTS THE COMPASS.

BY

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PREFACE.

I have thought to render a service to those who handle iron ships, by exhibiting in a concise form the principal phenomena of the deviations of the compass—such a work, free as possible from technical terms, as by a few hours' reading will afford an intelligent grasp of the subject.

For its comprehensive treatment, many excellent works exist, which of course must be consulted.

In the following pages I have first described the characteristics of a steel magnet, the method of determining these characteristics for any particular one, and the reciprocal action of two magnets. The similitude of the distribution of the magnetism in an iron or steel ship to that in an ordinary bar-magnet is next established, and by an amplification of the method of examining the steel magnet, the inquiry is made applicable to the ship, whereby we may become acquainted with her magnetic peculiarities: these for an actual case—that of the U. S. S. Ranger (iron)—are next given, and they forcibly point the importance of the inquiry.

Following this is a series of experiments illustrative of the physical facts upon which the mathematical theory of the deviations of the compass is based; next are the results of two experiments—one to show the effect of the

magnetism of the ship on various types of compass whose needles differ in length, weight, number, and place of attachment to the card; and the other, the effect due to placing the same type of compass in different parts of a ship. The work closes with three experiments on the compensation of compasses, and some remarks on induced magnetism. I have used throughout, the same notation and technical terms that have long been employed in mathematical treatises on the deviation of the compass.

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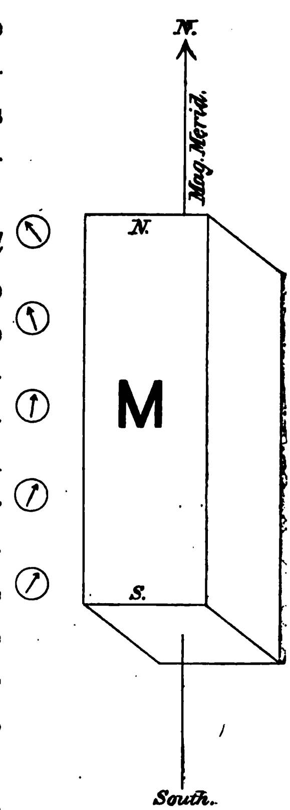
Washington, October 22, 1884.

THE MAGNETISM OF IRON AND STEEL SHIPS.

(1.) The distinctive features of a magnet are two poles of dissimilar nature and equal strength, separated by a neutral ground over which neither pole holds sway. To determine these characteristics for any particular magnet requires a series of observations which, in a general way, may be described as follows:

Fig. 1.



(2.) *To locate the poles and neutral lines:* Let M, Fig. 1, represent a large bar magnet laid horizontally in the meridian. It is in the midst of terrestrial magnetism, but for the space considered this is of uniform strength, and so may be dismissed from view. For some space around the magnet, however, there is a field of variable force controlled by the magnet itself; the variability of this field from point to point, will be an index of the magnet's power, and we will so explore it.

Take a small compass whose needle, about an inch in length, is free to move in a horizon-

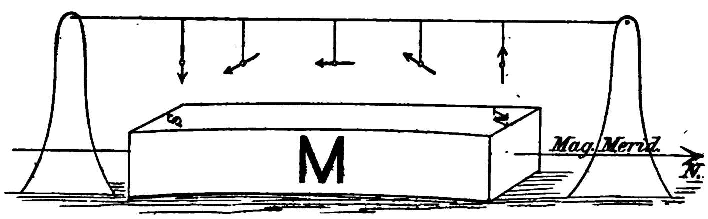
tal plane only, and place it successively at equal distances along a line parallel to the magnet, at a constant distance from it, in the plane of its upper face. The needle will show a deflection varying with each station.

Make another series of observations, at like intervals, along another line equally distant from the magnet, but on a plane a little below the upper face, and continue to do so until arriving on a level with the lower face of the magnet. Repeat these observations on the opposite side. We shall thus obtain a series of values, with coördinates for plotting them, which will determine the location of the poles and their dividing line; for where the deflection of the compass is greatest, *there* will be the focus of magnetic action, and it is evident that the more closely the points of observation are taken, the more accurately we shall attain the object sought.

(3) *To determine the strength of the poles:* If a pendulum be drawn aside, it will oscillate, and the force of gravity is the power that continues the motion. If the pendulum be taken to considerable height above the earth's surface, its period of vibration will differ from that on the surface. The period of vibration may, therefore, at variable distances, be taken as an index of the power at those distances. Conversely, if the power varies, the period of vibration at a constant distance will be an index of the variability of that power. The force of magnetism may be regarded like the force of gravity; and the period of vibration of a magnetic needle, in different parts of a variable magnetic field, may be taken as an exponent of the strength of the magnetism at that point.

Let M, Fig. 2, represent a very large magnet laid horizontally in the meridian; at equal distances above it, let a small magnetic needle, free to move in every direction, be suspended by a fiber of silk attached to its center of gravity. The small needle will assume different inclinations—the directions of the "lines of force" as shown, for example, in the figure. The magnetic field of the earth

Fig. 2.



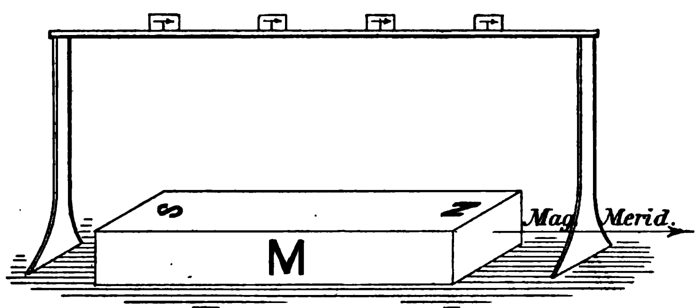
for the space considered being uniform, and the magnetism of the small needle constant, we need concern ourselves only with the variable effect, at different points, of the magnet M. The time of vibration of the small needle across a line of force will vary with the point it occupies along M.

(4.) For the purpose of investigation it is more convenient to determine the intensity of the power, not in the direction of the line of force, but in two other directions, the horizontal and the vertical. The first is accomplished by having a needle mounted on a pivot, and the inclining force of magnetism balanced by a weight, so that the needle may have motion in a horizontal plane only.

Vibrate the needle under the influence of terrestrial magnetism alone. Then, as in Fig. 3, place it at successive points on a board sufficiently elevated above M to

prevent this magnet reversing the direction of the small needle (yet near enough to have some effect), and vibrate it. The magnet M is supposed to be *very* large in com-

Fig. 3.



parison with the vibrating needle. Note the times of vibration with a stop watch, and take a large enough series to reduce errors of observation.

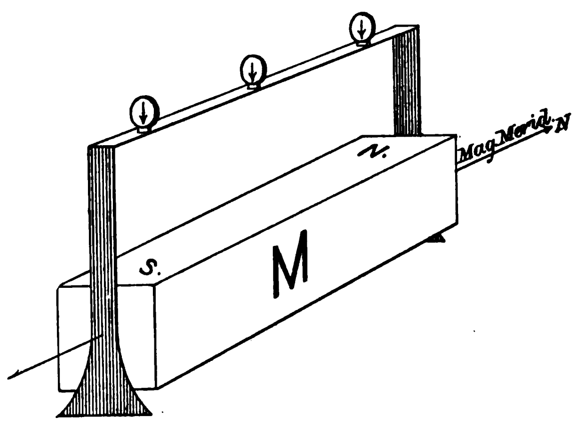
The times of a certain number of vibrations at different points will be unequal; they are affected by the constant magnetism of the earth (constant for the space considered), the constant magnetism of the vibrating needle, and the variable field at different points of the magnet M; and the effect of this magnetic field will vary inversely as the squares of the periods of vibration. The period due to the earth alone—which may be assumed as unity—we already have; the series above the magnet gives the sum of the earth and magnet M, whence the value of the magnet alone at each point becomes known.

(5.) A similar process will determine the vertical component. For this, however, we require a needle with a delicate axle rigidly attached to it through its center of gravity, so that it may be rested on smooth knife edges and made to vibrate in a vertical plane.

A single needle, such as that possessed by the Bureau of Navigation, and so contrived as to be susceptible of motion in either a horizontal or vertical plane, at will, is the most convenient.

When the axle points in the direction of the magnetic meridian, the needle stands transverse to the meridian, and will vibrate under the influence of the vertical component of the earth. Vibrate it thus to determine the

Fig. 4.



value of the earth; and then, as in Fig. 4, do the same at different points above a very large magnet, M. Then values of the vertical component are obtainable in a manner entirely similar to those of the horizontal component.

(6.) Much confusion has arisen from the different ways of regarding the earth's magnetism. Some writers designate "north" polarity that which pervades the region of the geographical north; whence it follows that "south" polarity must exist in the end of a compass needle pointing to this pole. Others give the names the converse of this. Although the first is the more natural,

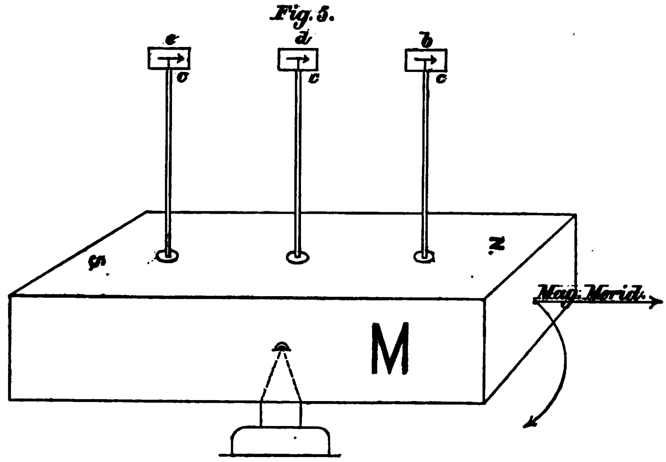
as the great magnet, the earth—rather than a lesser one—should give the name to the polarity, still I shall follow the second practice; since, from our use of magnetic instruments, we are accustomed to consider north polarity as that existing in the north end of the needle.

From this point of view, south polarity will pervade the region of the earth's north pole; it will induce north polarity in the lower ends of vertical iron and south polarity in the upper ends.

(7.) To ascertain the effect of a very large bar magnet upon a very small compass needle, let us direct our attention to Fig. 5.

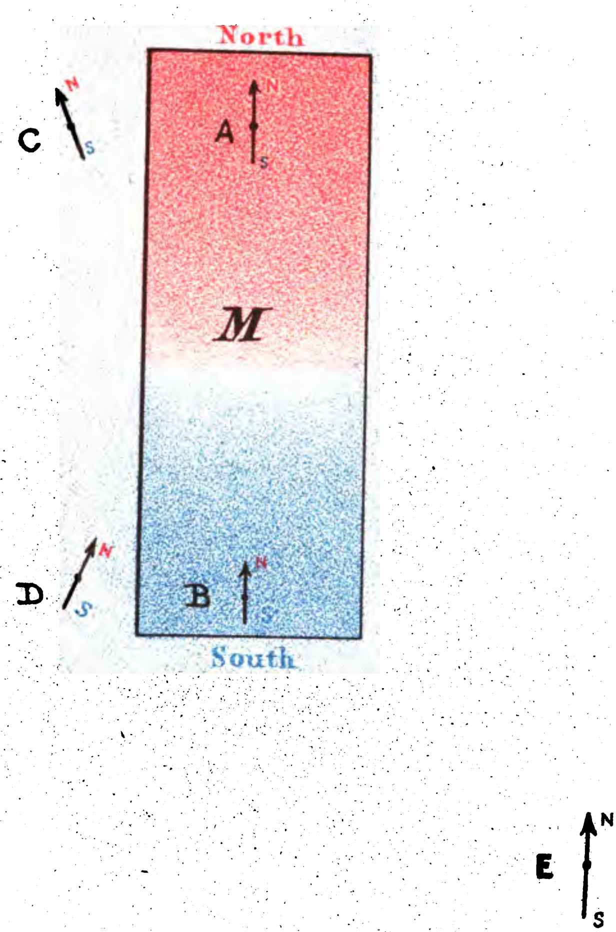
The magnet M lies in the meridian, its north pole to the northward. Place the compass *c* above it at *b*, high

Fig. 5.



enough to prevent its needle being reversed, yet within the influence of M. Reciprocal action takes place as follows: the north pole of M repels the north pole of *c* and attracts its south pole, while at the same time the south pole of M attracts the north pole of *c* and repels its south

Fig. 6.



pole, all of which causes unsteadiness of the compass. Place the compass at *e*, and action entirely similar, with consequent restlessness, will ensue. Place it at *d*, and the effect will be the same in kind though different in degree. There is also a difference in degree between the positions *b* and *e*, if we suppose M long enough to have the distant pole, the south pole, for example, exercise but little sensible effect upon *c* when placed at *b*; for below *b* is a large body of north polarity, a polarity of opposite kind to that of the earth around it (in the northern hemisphere), and so constituting an absorbent of the lines of force emanating from the earth. The magnetic current, so to speak, is partly closed, and hence the result is a weakening of the directive force of the earth on the compass.

At *e*, on the other hand, we have a large body of south polarity below *c*. True, by its attraction of the north, and repulsion of the south end of *c*, it creates unrest, but, being of the same kind as the surrounding terrestrial field, closes no current, absorbs no lines of force; and this constitutes the degree of difference.

The adjoining Fig. 6 will render this more clear. It represents a long, thin, wide magnet, M, placed in the midst of terrestrial magnetism, which in this hemisphere, according to the convention of paragraph (6), is of south (blue) polarity. Suppose a compass needle to be placed at E under the influence of this field alone; it will point in the direction of the magnetic meridian, parallel to the surrounding (blue) lines of terrestrial force which give it direction, and, if set in vibration, will require a certain period, say 19.^{s}3, to make ten oscillations.

Place this needle at B over the south end of the magnet: the (blue) lines of force which give it direction are increased, the needle is steadier, and, if set in vibration, will move more quickly and perform ten oscillations in a shorter period, say $18^s.9$. Place the needle at A over the north end of the magnet: the (blue) south lines of terrestrial force are partly absorbed by the (red) north lines of the magnet's force—the magnetic current is closed—the directive power is weakened, the needle is partly brought to the astatic condition, and hence will move more slowly and perform ten vibrations in a longer period, say 21^s. At A and B, of course, the needle must be placed high enough not to have its direction reversed by the powerful magnet, yet sufficiently low to be within the magnet's influence.

It is, therefore, a matter to be considered where we put the needle above M. Turn M, Fig. 5, on its pivot through 180°, so that its south end shall be to the terrestrial north, and then all the reciprocal action produces greater steadiness of the compass, above whichever part of M it be placed. Thus it is all important what direction M itself may take.

(8.) As all that precedes is merely for illustrating the principles involved, I omit details, corrections, and modes of observation which enter into the practical performance of the work.

(9.) An iron, as well as a steel ship, is itself a magnet, possessing in common with even the smallest sewing needle (when magnetized), two areas of opposite polarity separated by a neutral line. It has become a magnet through the inductive agency of the earth's natural magnetism,

aided in its action by the enormous amount of percussion to which the vessel is subjected in building.

This large floating magnet is to be guided in its wanderings round the globe by a rather diminutive one—a compass needle—upon which it oft-times depends for safety. From the foregoing examination of a magnet, it is evident that we may not put the guiding needle at random on the ship; for if within reach of one of the powerful poles of the vessel, the survival of the strongest is the result, and the compass goes round and round heedless of the salutary directive power of the earth.

It does not lead—it misleads. Moreover, it is not alone the centers of the two grand areas of opposite polarity existent in the hull that must be avoided; many minor ones lie hidden in the net-work of the interior structure, and the needle must be kept out of the influence of these, or its usefulness is gone.

To discover these pitfalls, large and small—to place the compass where vicious influences will least affect it, and to determine accurately the kind and degree of the pernicious surroundings that it must of necessity have—is the object of a thorough magnetic examination of an iron ship.

I shall endeavor to describe concisely the mode of procedure, illustrating it by an example from an actual case—that of the United States steamer RANGER. The data relative to the RANGER will be found further on.

(10.) To find the poles and neutral line of a ship is but an amplification of the procedure already described with reference to a bar magnet (2).

The occasion of placing a vessel in dry-dock for any purpose whatever, affords the opportunity for making the observations.

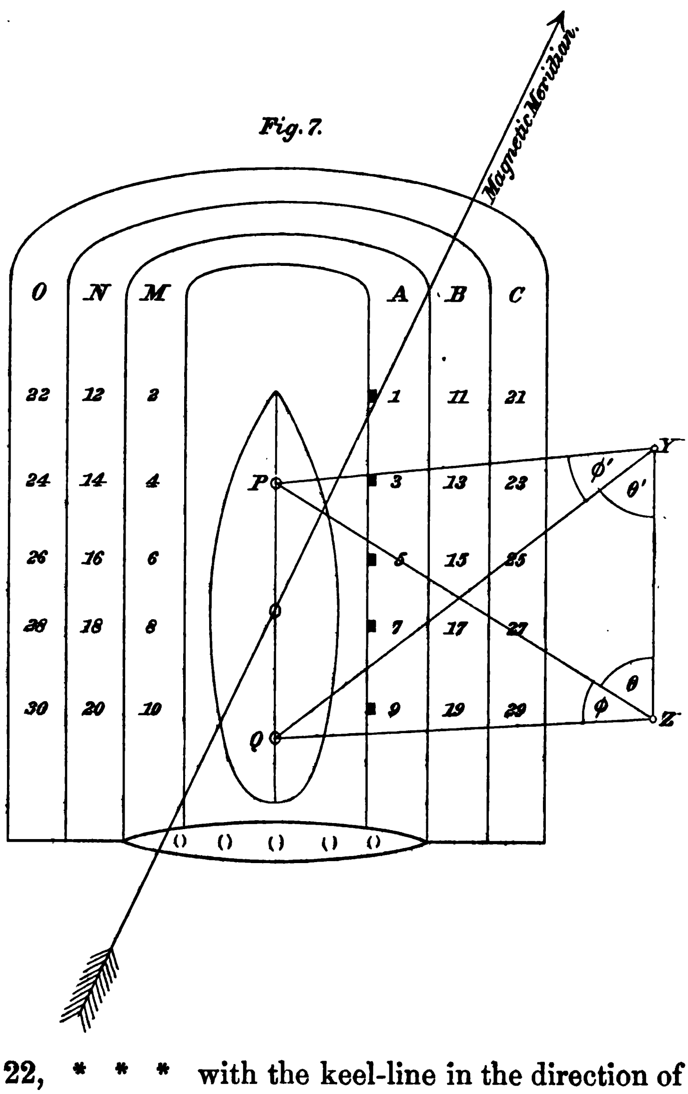
The vertical height of each step of the dock above the keel, measured intervals of its length, and the horizontal distance from the ship's side, constitute co-ordinates for plotting the values found. As qualitative, rather than quantitative, results are the special object of this part of the inquiry, it is evident that some error in the amount of the observation is admissible. For example, if we are sure that the deflection of the compass at any particular station is west, it matters little whether it be a degree or two more or less westerly; the fact that it is west decides the kind of polarity, and that is mainly the point we are in quest of.

Let Fig. 7 represent a plan, and Fig. 8, a section of a vessel in dock. The direction of the magnetic meridian is first determined, or rather (what we really wish to know) the angle that the keel of the ship, and consequently the line of the steps (as the keel may practically be considered parallel to them), makes with the meridian. Many methods are available for this, but the following is simple and will suffice: find a line, $z\,y$, from the extremities of which reciprocal bearings by an azimuth compass are identical; measure this line, and measure also the angles θ, θ', φ, and φ', to any points in the midship line of the vessel; from these data the required angle may be found either by computation or construction.

Then, on each of the steps A, B, C, * * * M, N, O, * * * measure distances of 20 to 25 feet, and number

the points with chalk. Carry a compass in its box suc cessively to each station; place the box with its side parallel to the edge of the step, as at 1, 11, 21, * * * 2,

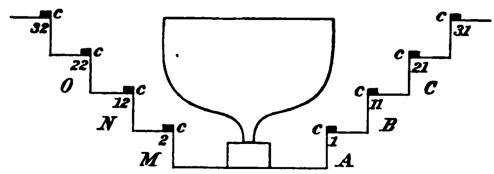
Fig. 7.



12, 22, * * * with the keel-line in the direction of the bow, and when the compass has come to rest, observe and record the reading.

A comparison of the readings with the magnetic direction of the steps will give the deflections of the compass caused by the ship—those in one direction denoting north

Fig. 8.



polarity, and those in the other direction, south polarity. These results are to be represented on side views of the ship.

When the dock is clear, observations are taken at each station to determine the effect of any iron that may lie hidden beneath the masonry; then a comparison of the two series—with and without the ship—gives the effect of the latter.

The steps are at unequal distances from the ship's side, which precludes a strictly quantitative comparison, but generally the magnetism is strong enough to leave no doubt as to its kind, the area of its greatest intensity, and the line in which it shades off to neutrality.

(11.) While the ship is in dock is the time to make such observations as will determine the most suitable location for the compasses, and the magnetic character of their surroundings; and this can be done with much confidence in the results, although only on one heading of the vessel. A portable stand for holding the instruments is set up at practicable points along the midship line from bow to stern. At each station the following are observed:

First. The deviation of the horizontal needle.

Second. The period in which this needle makes ten vibrations through a moderately small arc.

Third. The period of the vertical needle making ten vibrations when free to move transversely to the magnetic meridian.

Fourth. The dip and period of ten vibrations of this needle when free to move in the vertical plane through the keel.

Fifth. The dip and period of ten vibrations of this needle when free to move in the vertical plane transverse to the keel.

The observations of the 2d and 3d cases are repeated on shore in a spot free from local attraction, and also those of cases 4 and 5, care being taken for these to have the instrument turned into the same azimuth as on board. From a comparison of the series on both ship and shore the effect of the ship alone is readily obtained.

We are now enabled to place in tabular form, for the several stations, the Deviation, the Horizontal and the Vertical Force, and the Dip and Force in the plane of the keel and transverse to it—all the phases in which the disturbing force of the ship can manifest itself; and it only requires careful comparison of these data, and good judgment, to select the site least objectionable magnetically.

When this is decided, a number of like observations are made in the immediate vicinity of the spot, to determine fully its magnetic character.

And thus we establish the fact whether it is the large magnetic field of the hull alone we have to contend with,

or the concentrated but often powerful pole of some individual piece of iron.

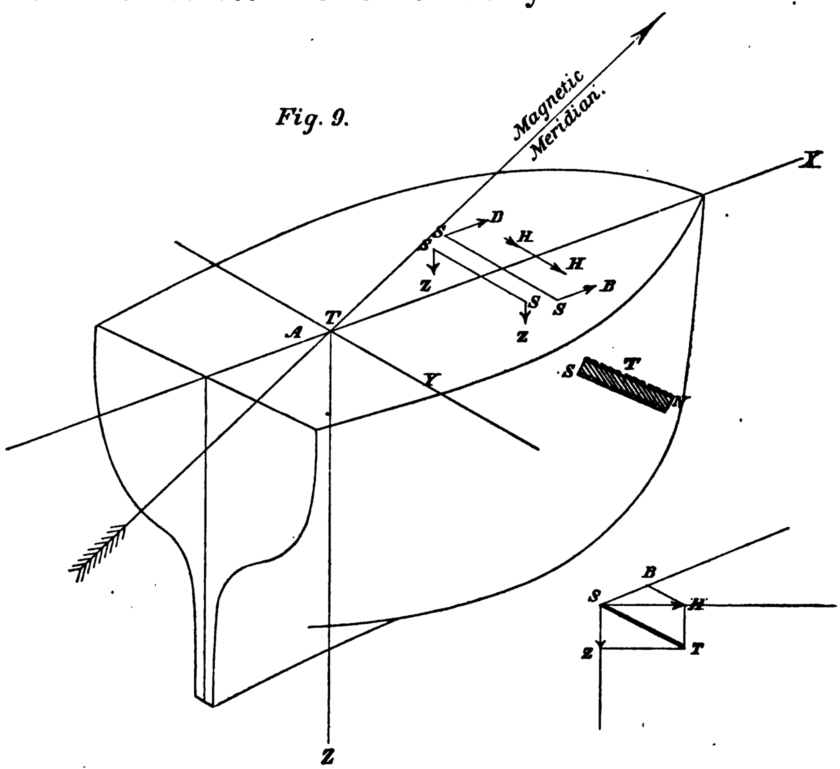
Were the observations made at each of the stations along the deck, while the ship is swung at compass buoys in smooth water, and steadied successively on eight equidistant points, the diagnosis of the case would then be thorough—complete.

(12.) The magnetic effect of a ship may be considered as taking place in three co-ordinate axes, namely, fore-and-aft, athwartships, and vertically downward, with the compass-pivot as the origin. To facilitate this conception, let us contemplate Fig. 9, and let T represent a bar of iron of such quality that when held upright it becomes instantly magnetic through the induction of terrestrial magnetism, and as instantly has its polarity reversed upon turning it end for end; in other words, what, in investigations of this kind, is technically known as soft iron. Let this bar, supposed to be anywhere in the interior structure of the ship, take the most general position possible, *i. e.*, inclined to the plane of the deck, and also to that passing vertically through the keel.

As already stated, reciprocal action occurs between the magnetism of the bar and that of the compass needle; the upper end of the former (in this hemisphere) attracts the north end of the needle and repels its south end, while, at the same time, the lower end of the bar repels the north end of the needle and attracts its south end. The difference in distance, however, between the near ends of the bar and needle and their remote ends, enters to such extent that the influence of the remote only modifies, not equals,

that of the near ends; the net result may be stated as one of action between the near ends only.

Fig. 9.



We have thus to deal with but one kind of the bar's polarity: represent its force by a line of definite length, ST, for example. This force is resolvable into two others, the horizontal SH, and the vertical SZ; and the former is further divisible into SB, parallel to the midship line, and BH transverse to it. The magnetic power of the bar is thus resolved parallel to the three co-ordinate axes. Almost all the structural iron of the ship—beams, knees, engines, boilers, &c.—is symmetrically arranged with reference to the vertical plane through the keel; so that

for a piece T on the starboard side, we should generally find another similarly disposed on the port side.

The problem is now simplified to pairs of parallel forces, each pair having its resultant parallel to one of the co-ordinate axes; and the effect of every magnetic particle, whether of permanent or transitory magnetism, may be reduced to this condition. We may now with facility transfer into each co-ordinate axis the sum total of all the forces parallel to it, and concentrate the whole upon the north point of the compass; whence the final result, that we have reduced the entire magnetic power of the ship to that of three imaginary magnets—one laid horizontally in the axis of X; the second, also horizontal, in the axis of Y; and the third, vertical, in the axis of Z.

(13.) The individual and combined effect of these three imaginary magnets we shall now study; but, before doing so, it will be necessary to remark that each is not simple, but complex, and that, recognizing this, we shall have to consider *all* the component parts, leaving to every *real* case to determine which of the components reduce to zero, and which are prime factors.

The iron of a ship is of varied quality, from the "hard", which, when hammered, acquires and keeps its magnetism, to the "soft," which has absolutely no retentive power. It occupies every conceivable direction—vertical, longitudinal, transverse, and inclined at diverse angles; but, however varied the latter, it may be represented in the first three directions by pieces of equivalent effect. Finally, it may be symmetrical or unsymmetrical.

To cover all the conditions of the problem, we shall choose representatives of quality and direction, of symmetry and singularity, and let each assert its power in the common struggle.

(14.) Fig. 10 represents the arena of these forces: they are arrayed in lines of attack upon the compass. P, Q, and R represent hard iron, whose magnetism, the result of percussion, is of a permanent nature, like that of a steel bar. The law of its influence in producing deviation of the compass is that of the ratio of a constant to a variable force; hence, as the ship traverses different regions of the globe (which have variable directive power), the deviation of the compass, due to hard iron, will vary inversely as the horizontal force of the earth.

(15.) *c*, *f*, and *k* represent vertical soft iron; it becomes magnetic through the inductive agency of the earth's vertical force, and its effect will vary directly as this force—that is, as the magnetic dip.

(16.) *a*, *e*, and *g* represent horizontal soft iron, the first and last, when in a longitudinal direction, and *e*, in a transverse direction; its power is derived from the inductive agency of the horizontal force of the earth, and varies directly as this force.

(17.) *b*, *d*, and *h* are substitutes for an isolated mass, like T, that has no counterpart on the opposite side, and they proclaim T's influence in every direction to which that extends. Soft iron, and both horizontal and vertical induction, are T's characteristics.

(18.) In all cases of iron which becomes magnetic through the mild inductive influence of terrestrial mag-

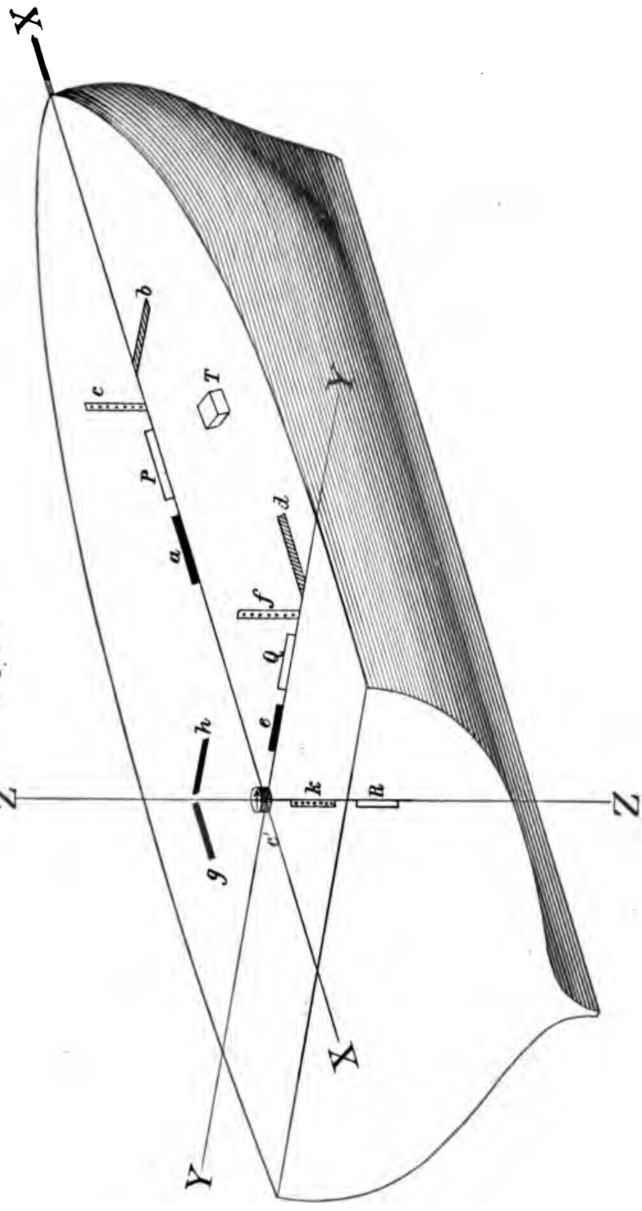


Fig. 10.

netism, it should be remembered that this influence may be variously modified, if, indeed, not in some instances entirely superseded, by the inductive action of a powerful surrounding field of permanent magnetism in the hull itself.

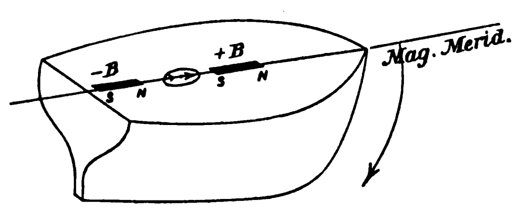
(19.) According to the location of the bulk of each class of iron—the hard and the soft, the vertical, longitudinal, transverse, and unsymmetrical—its resultant or representative, which we may designate as a rod or a bar, will occupy a position relative to the compass, either forward or abaft, to starboard or to port; and all such possible positions are shown in Plate I.

(20.) We are now prepared to inquire into the effect of the different rods and bars, and this I shall do for only one position of each class of iron, since the phenomenon will be rendered applicable to all positions by merely giving the proper algebraic sign to suit the circumstances of the case.

(21.) Both the hard bar P and the soft rod c, Fig. 10, although of such different origin, and so divergent as to the laws governing their influence, yet produce entirely similar effects, and may therefore be considered together. Designate their joint action by B, Fig. 11, plus (+) when

Fig. 11.

$B = P + c.$



forward of the compass, minus (—) when abaft. First,

suppose attraction to take place between B and the compass, that is, the south pole of + B or the north pole of — B directed toward the needle, with the ship's head magnetic north.

As the ship swings out of the meridian toward the right, B causes the needle to deviate, also toward the right, by constant increments at each remove, until a maximum is attained as the vessel revolves through 90° of azimuth; the revolution continuing, the needle returns by constant decrements toward the meridian, and reaches it as the vessel finishes a semicircle. Let the ship complete the circle, and the needle will but describe a path symmetrical to the first, on the opposite side of the meridian.

Fig 12.

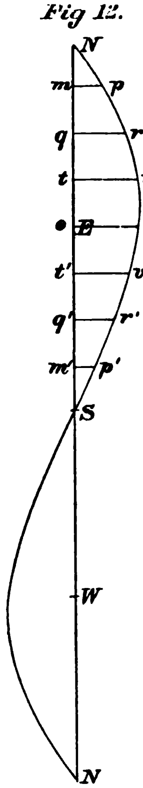
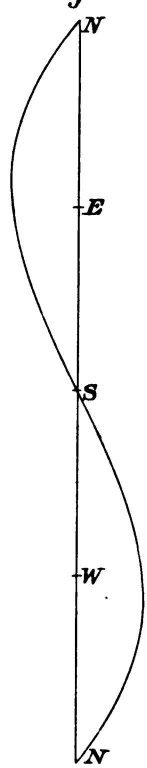


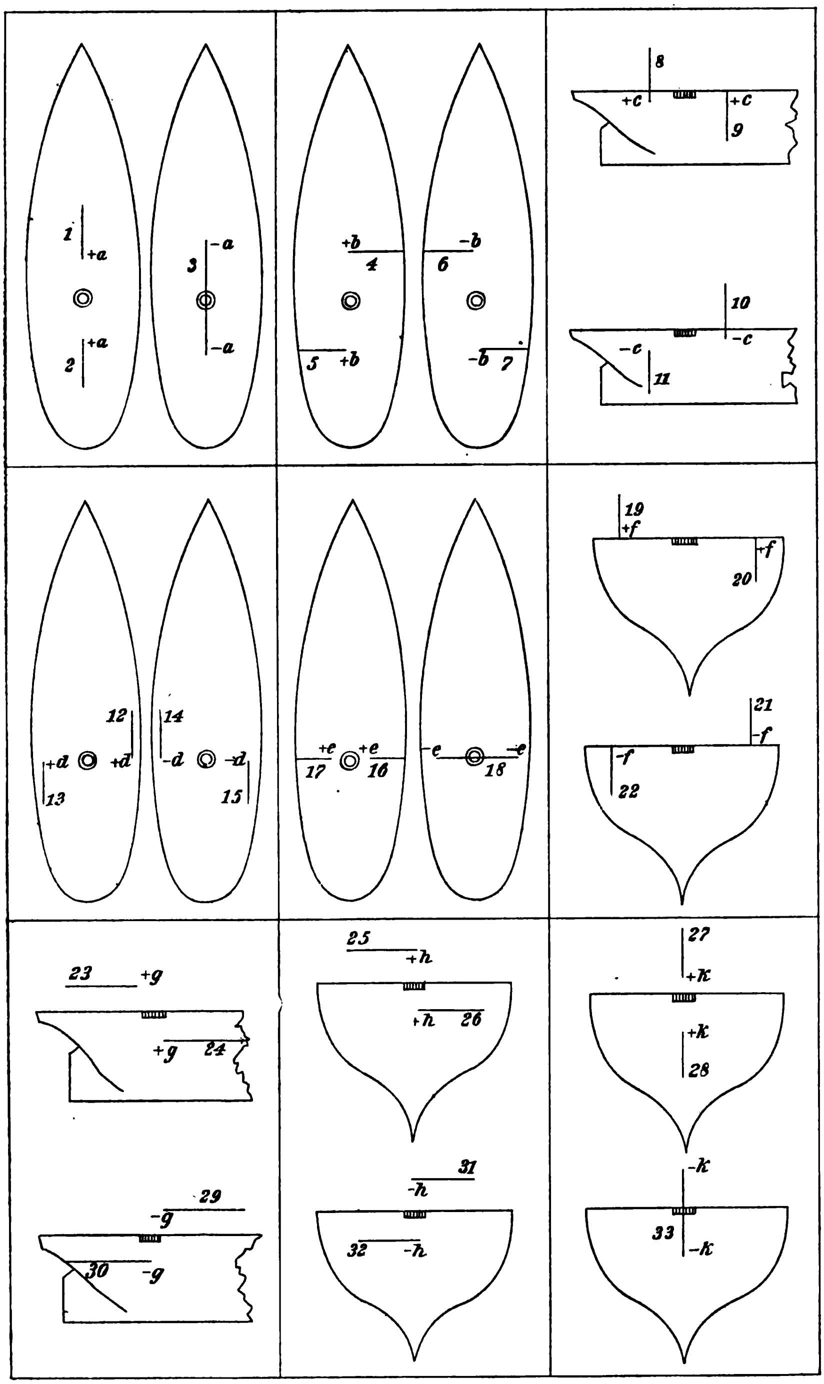
Fig. 13.



(22.) To represent graphically the path of the needle, unfold the circumference of the compass card, and straighten it into the line N E S W, Fig. 12; equal distances (abscissæ) along this line from the origin N, as *m q*, *q t*, &c., will represent equal azimuths of the ship while swinging; from the extremity of each abscissa erect an ordinate, as *m p*, *q r*, &c., equal on any scale of parts to the deviation of the needle for that azimuth; draw a curve through the extremities of all the ordinates, and the result is a wavy line having maxima at east and west and minima at north and south.

PLATE I.

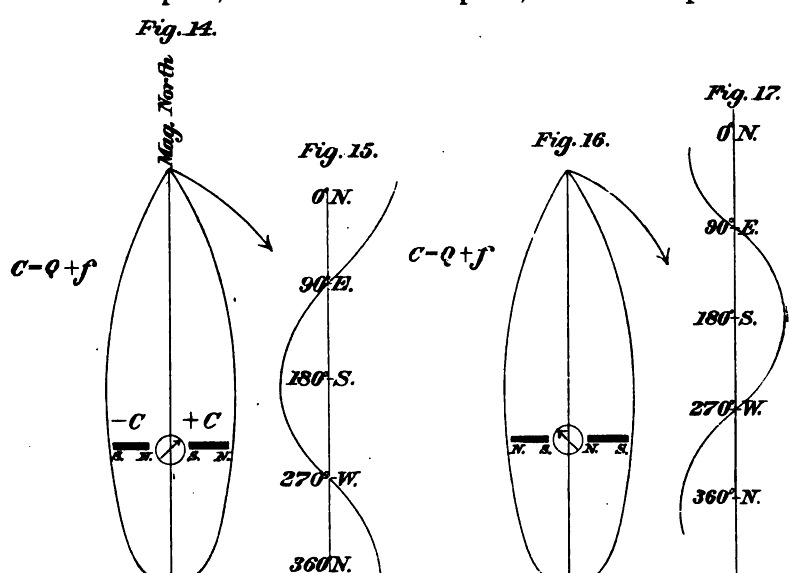
Diagram showing the positions of the nine soft iron rods which represent the whole of the soft iron of a ship as regards its action on the compass.



The curve is thus seen to be a function of the azimuth, swelling and flattening as that increases; more than this, it is 0 when the azimuth is 0°, and steadily grows to a maximum when the azimuth is 90°—the characteristic feature of the trigonometric sine of an angle. Denote the azimuth by ζ', and then the effect of B on different azimuths will be represented by B sine ζ'.

(23.) If repulsion had taken place, then on the ship swinging, as before, out of the meridian toward the right, the needle would deviate toward the left, and trace the curve shown in Fig. 13.

(24.) In the transverse axis (Fig. 10) the bar Q, and the rod f, are the counterparts of P and c in the longitudinal; represent their joint effect by C, plus when to starboard of the compass, minus when to port; then the possible



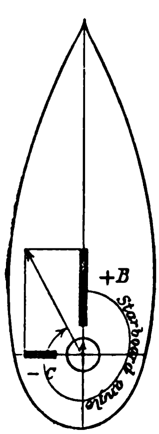
positions of C, with the resulting curves, are shown in Figs. 14, 15, 16, and 17.

They need no further explanation than to state the mutual relation of C and the azimuth.

In both figures, while the ship heads north, C exerts its maximum effect; as she swings out of the meridian, to the right, the needle returns by constant decrements to its normal direction, and attains it as the ship heads east; at south there is another maximum; and at west another minimum. Thus the effect is at its height when the azimuth is 0°, and at its lowest when it is 90°, which supplies at once the required relation—cosine of the azimuth—as the bond of union between C and ζ', that is, C cosine ζ'.

(25.) B and C form the two sides of a right angled triangle; the hypothenuse—their combined effect—is obtained by the expression $\sqrt{B^2+C^2}$. This is the greatest value of the semicircular deviation, so called because all its phases occur in a semicircle. According to the different positions of B and C and their relative strength, this resultant will point toward either bow, or either quarter, and the angle that its direction makes with the midship line (the compass being the center of angular measure, which is reckoned from 0° to 360°), is known as the "starboard angle." This is shown in Fig. 18, where B is plus and C minus, the former the stronger. The ship's semicircular force, in this case, lies in the direction of the port bow with a "starboard angle" of about 340°.

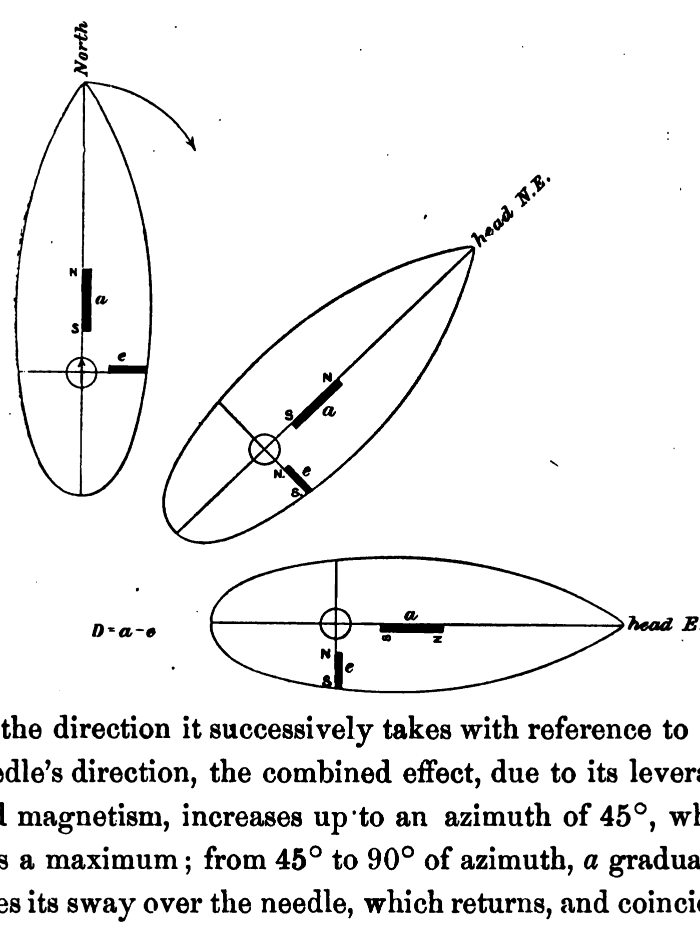
Fig. 18.



(26.) The rods a and e represent the longitudinal and the transverse soft iron; let us consider them in their relative positions shown in Fig. 19. While the ship lies in the

meridian, *a* receives its greatest charge of induced magnetism, but produces no deviation, being in the prolongation of the needle; *e*, on the other hand, has no magnetism, as it lies transverse to the inducing power. As the ship swings out of the meridian, *a* causes the needle to deviate in the same manner that + B did, with this difference, however, that while B retained its power intact during the swinging, *a* gradually loses its strength; but on account

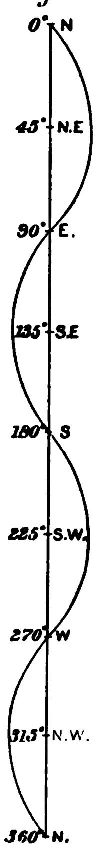
Fig. 19



of the direction it successively takes with reference to the needle's direction, the combined effect, due to its leverage and magnetism, increases up to an azimuth of 45°, when it is a maximum; from 45° to 90° of azimuth, *a* gradually loses its sway over the needle, which returns, and coincides with the meridian as the ship swings through 90°. But

this effect of *a* is somewhat modified by the action of *e;* on the ship swinging out of the meridian, *e* slowly becomes magnetic through the earth's horizontal inductive power, the end nearest the compass becoming a north, and consequently, a repellant pole, while the nearest end of *a* is an attractive pole; the effective result, then, is the difference of these two; represent it by D, and we have D = *a* — *e*. The sign of D will depend on the relative strength of *a* and *e*. With the ship's head east, *a* loses all vestige of magnetism, while *e* receives its maximum charge, and thus they alternate between weak and strong, according to which one coincides with the magnetic meridian, and which is transverse to it. We will follow them in their common resultant D round the circle. From 90° to 180° the curve traced between 0° and 90° is repeated, but now on the opposite side of the meridian; from 180° to 270° we have the same curve as from 0° to 90°, while finally, between 270° and 360°, the same as from 90° to 180° — in fine, the wavy line of Fig. 20. Its general contour is that of the curve produced by B, alternate maxima and minima with symmetrical branches on each side of a central line; but as each of these characteristic points occurs four times in the curve produced by D, and only twice in that produced by B, it is evident that the effect of D, considered as a function of the azimuth (which it is just as the effect of B is such a function), may be represented by D sine 2 ζ'.

Fig. 20.



(27.) As before stated (17), the rods *b*, *d*, and *h* are the representatives of an unsymmetrical mass of iron T (Fig. 10); *h* being a factor of the "heeling error," its effect will be considered when treating of that.

(28.) It now only remains to deal with *b* and *d*—the last components of the power that produces deviation with the ship upright; we will follow their action in Fig. 21.

Fig. 22.

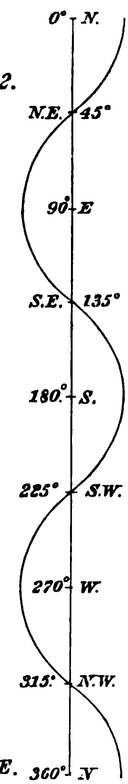
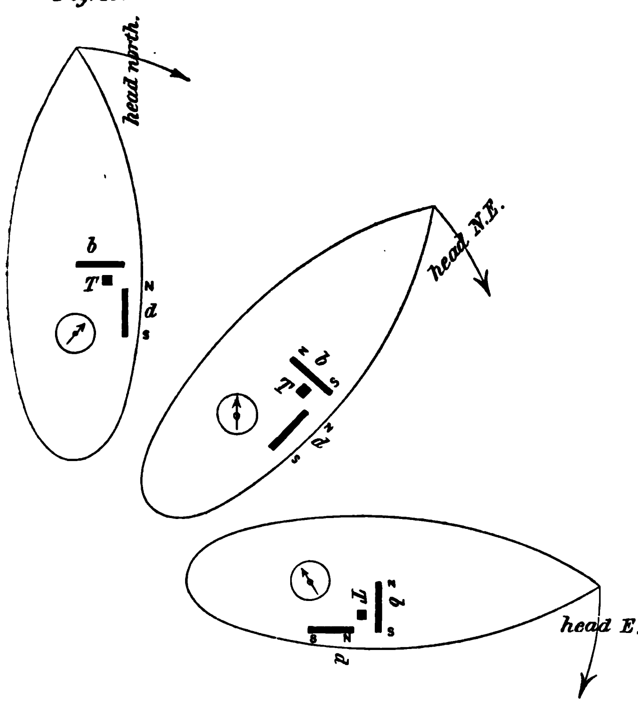


Fig. 21.



$E = b + d.$

With the ship's head north, *b* is inoperative through want of magnetism, for it lies transverse to the inducing power; *d*, on the contrary, has its maximum strength and

produces its greatest deviation—toward the right. As the ship swings out of the meridian, *b* slowly acquires, and *d* as slowly loses, its magnetism. Moreover, the acting pole of *d* is attractive while that of *b* is repellant. With the ship's head NE., these two forces are equal—they balance—so that while their varying powers have been progressing to this state of equilibrium, the needle has gradually returned to the meridian. The ship continuing to turn toward the right, the balance is once more disturbed; *b* now preponderates, repelling the needle more and more, and *d* grows weaker and more feeble, until, when the ship heads east, its last vestige of strength departs, and *b* alone is all-powerful, repelling the needle to the limit of its path.

The revolution continuing, we have but a repetition of the alternate domination of *b* and *d*, the latter at south, and the former at west. Thus there are four maxima at the cardinal points, and four minima at the intercardinal; in a word, the curve of Fig. 22. Represent this concurrent effect of *b* and *d* by E; then, as in the case of C (24), since the effect of either rod alone is greatest when the azimuth is 0°, and least when this is 90°, its law of variation would be that of the cosine of the azimuth; but, as both must be considered jointly, being the parts of one mass, and as the maximum takes place at 0° and the minimum at 45°, their case is entirely analogous to that of D, whose rate of change, it has been seen (26), is as the sine of twice the azimuth. Hence the mathematical expression for *b* and *d* is E cosine $2\,\zeta'$.

(29.) The resultant of D and E, similarly to that of B

and C (25), is obtained from the expression $\sqrt{D^2 + E^2}$: it is known as the quadrantal component of the total deviation, because all its phases occur in one quarter of the circle. For the same ship it is theoretically constant—unchangeable with either time or place—and the numerous analyses I have made of ship's deviations confirm the

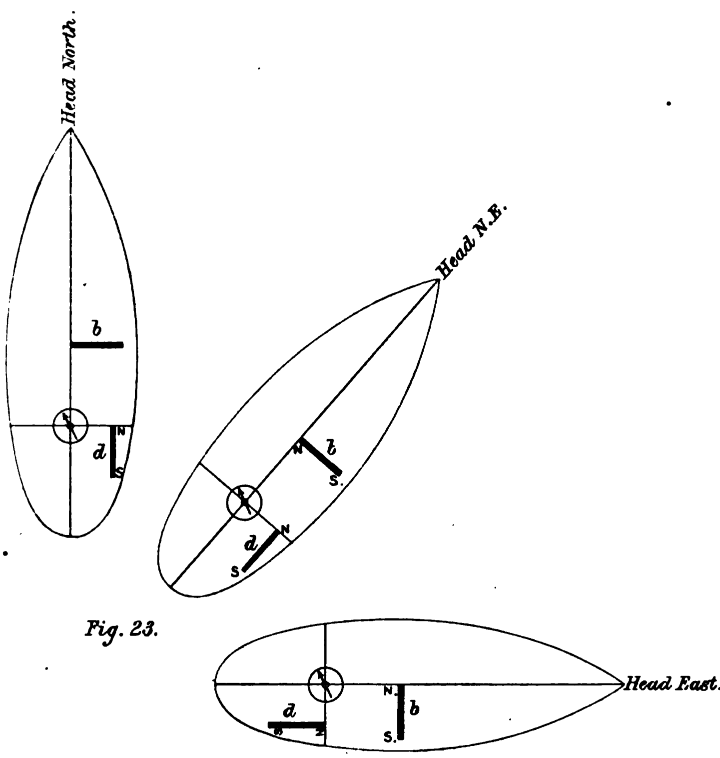


Fig. 23.

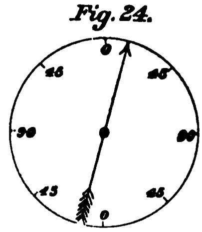
theory for all practical purposes. The reason of the constancy is this: the quadrantal deviation is caused by the inductive action of the horizontal component of terrestrial magnetism on soft iron laid horizontally; it is this same horizontal component that gives direction to the compass needle; consequently any change in the disturbing force

is followed by an equal change in the directive power; hence their ratio is a constant.

(30.) But one more term of the total deviation remains to be explained. If the joint action of the rods *b* and *d*, as placed in Fig. 23, be followed, it will be found that it causes an unvarying deflection of the needle in all azimuths of the ship; that is, the deviation from this source is independent of the azimuths.

Again, the magnetic axis of the needle may not coincide with the zero-line of the card, as in Fig. 24, and this likewise is independent of the azimuth. Other errors of similar nature may exist, and all such are represented by A, known as the constant deviation.

Fig. 24.



(31.) Now denoting the total deviation by δ, and collecting its scattered parts which have been explained in paragraphs (22), (24), (26), (28), and (30), we have—

$$\delta = A + B \,.\, \text{sine}\ \zeta' + C \,.\, \cos.\ \zeta' + D \,.\, \text{sine}\ 2\,\zeta' + E\ \cos.\ 2\,\zeta',$$

the mathematical formula of the deviations of the compass I have arrived at it by the synthetical method—studying the physical phenomenon produced by each component, and then combining the whole.

This is the empirical process—an easy path for those who have neither the time nor inclination to traverse the customary route that leads through a circuitous and elaborate intricacy of trigonometric formulæ—the transformations of Poisson's equations by Archibald Smith.

(32.) Each component of the total deviation produces *by itself* a regular and symmetrical curve; it is the com-

bined action of all—their superposition, that gives rise to the irregularity so often seen in actual cases; and according to the varying strength of each component, we shall have every variety of the general type of curve; moreover, by its algebraic sign, which appears in the analysis of a table of deviations, we may infer the location, with reference to the compass, of each part of the three imaginary magnets we have chosen as representative of the disturbing power of the ship. A, B, C, D, and E are called the magnetic coefficients.

(33.) In order not to convey an incorrect impression, I must state that the formula given above (31) is not complete.

The phenomenon of the deviations of the compass is a periodic one; let the ship circle round and round, as often as she will, under the same conditions, and nothing new will be elicited—all the phases have appeared in the first circle. Fourier's theorem gives expression to such a state of affairs; as adapted by mathematical treatment to the case of compass deviations, it takes cognizance, not only of the constant, the semicircular, and the quadrantal components, summed up in the equation of paragraph (31), but also of all others; the sextantal, which has six maxima and six minima in a complete swing, the octantal, which has eight such distinctive points, and so on; it is, in fact, an infinite series of the form

$$\delta = A + B \cdot \sin \zeta' + C \cdot \cos \zeta' + D \sin 2\,\zeta' + E \cos 2\,\zeta' + F \sin 3\,\zeta' + G \cos 3\,\zeta' + H \sin 4\,\zeta', \&c.,$$

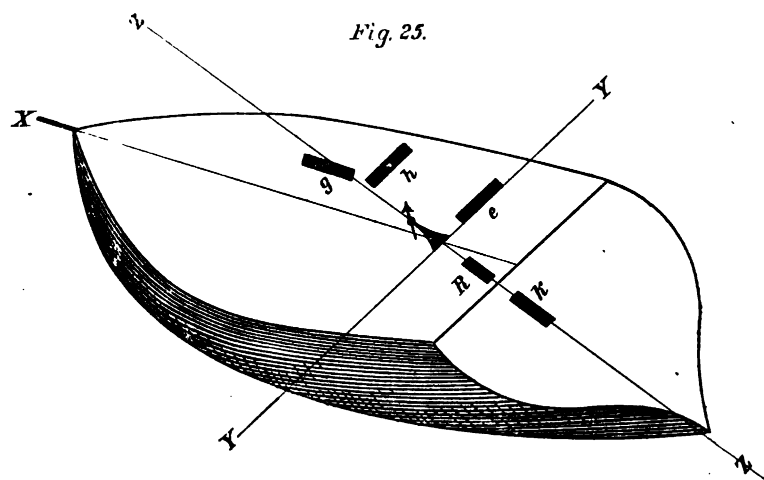
but so rapidly converging that for deviations of the ordinary amount, its first five terms (composing the equation

which has been explained), cover all the errors that need practically be considered.

(34.) Thus far the disturbing force has been treated with the vessel in an upright condition only, but when she lists to either side, a new and additional cause of deviation arises — the "Heeling Error."

This is caused by the imaginary magnet in the axis of Z (Fig. 25) together with the rod *e* in the axis of Y. When

Fig. 25.



the ship heels, *e* can no longer be classed among the representatives of horizontal soft iron as in (16); it partakes of the vertical nature, the lower end becoming charged (in this hemisphere) with north, and the upper end with south magnetism, in all azimuths of swing; the acting pole of this rod, whether attractive or repellent, will depend for each particular ship upon which of the general positions of the rod *e*, shown in diagrams 16, 17, and 18, of Plate I, represents her transverse soft iron.

The rod *h*, the substitute of an unsymmetrical mass of soft iron, entirely resembles *e* in its action. The rod *g*,

which represents longitudinal soft iron (generally below the compass, but placed above in Fig. 25 merely for clearness of illustration), is at its height, magnetically considered, when the ship heads north or south, and has no polarity when she heads east or west.

The rod *k* represents vertical soft iron below the compass; its upper end, which is the one that always acts upon the needle, has south polarity. The bar R represents the permanent magnetism of the hull immediately below the compass. The actual state of the case respecting R and *k* is, that they are the resultants of forces symmetrically disposed with reference to a vertical section of the ship through the keel. Now, a magnet set vertically above or below the *pivot* of a compass, will attract its needle neither to the right nor to the left; but let this magnet become inclined to the vertical by the ship heeling, and its influence is declared at once by a deviation of the needle. R and *k* may either conspire or conflict in their action—it depends entirely on the polarity of R. Indeed, I may say that as each of the components *e*, *h*, *g*, *k*, and R has its own distinctive polarity, their resultant effect will be their algebraic sum.

This may attract the needle to windward, or repel it to leeward; in most ships the former is the case.

(35.) In paragraph (11) it was stated that if vibration experiments with horizontal and vertical needles were made with the ship on one heading, her magnetic force for that heading would be obtained; if this be done for a number of equidistant headings (since we have seen by paragraph (7) that these values vary with the heading of

the ship), and the mean of all these values be taken, we thus obtain the mean horizontal force denoted by λ, and the mean vertical force denoted by μ. Both these quantities are essential in certain calculations of the ship's magnetism, and in predictions of changes of this, and of the changes in the deviations of her compass.

(36.) By swinging a ship under varied circumstances and taking the necessary observations, we arrive at the combined effect of the imaginary magnets in the axes of of X, Y, Z; that is, Tables of Deviations and values of Force; analyze these, and the numerical strength of each imaginary magnet is obtained; continue the disintegration, and the component parts—the magnetic elements of the ship—come clearly into view. With all these data supplied to a ship, the captain has before him all the varied forms of the disturbing magnetic force upon his compasses, and is enabled to predict how this will change and affect the deviations as he proceeds on his passage, to whatever latitude that may be.

And thus from EFFECT we have sought backward to an intelligent comprehension of the CAUSE.

This paper was written in January, 1884. During the month of May following, a series of observations were made by Lieut. John Hubbard and myself, to put to the test of experiment all the phenomena described in paragraphs (7), (10), (21), (22), (23), (24), (26), (27), (28), (30), and (34). The means employed was a model, which for convenience of reference has been named the Scoresby, after the investigator, to whom this branch of inquiry owes many of its established facts. It is mounted in the office of the Superintendent of Compasses. The results obtained with the Scoresby will be found immediately following the data of the Ranger.

T. A. LYONS.

JULY, 1884.

DATA RELATIVE TO THE UNITED STATES STEAMER RANGER.

The U. S. S. Ranger was built at Wilmington, Del., by Harlan & Hollingsworth; launched in 1874, completed in 1877; displacement when commissioned and ready for sea, 1,020 tons; length, 175 feet; beam, 32 feet; depth from rail to keel, 23 feet; iron beams and knees; wooden masts and yards; four transverse iron bulkheads.

On being commissioned she made a few passages between Norfolk and New York, then proceeded to the Asiatic Station via the Suez canal, stopping at Gibraltar, Malta, Port Said, Suez, Aden, Pointe de Galle, and Singapore. While on the station during the customary period, she visited the principal ports of China and Japan, and thence sailed for San Francisco, stopping at Honolulu on the way. During 1880–'81 she was repaired at the Mare Island navy-yard, California, and was subsequently employed on surveying service on the west coast of Mexico, where she is at present (1884).

With the exception of column 2, Table I, all the observations hereafter given were made by special direction of the chief of Bureau of Navigation, Capt. J. G. Walker, to Commander John W. Philip, commanding the Ranger.

For the observations of columns 2, 3, 4, and 5, the method of time-azimuths of the sun was used; for those of columns 6, 7, and 8, the method of reciprocal bearings, with a theodolite on shore, was employed.

The computations from which the results given in this paper are taken, were made by Lieut. John Hubbard. The name of the observer, and the circumstances and place of observation, are given in each case at the head of the column.

Plate IV represents the results of a magnetic survey of the vessel while on the sectional dock at the navy-yard, Mare Island.

The usual convenience of steps being absent, temporary stagings, a few feet from the ship's sides, had to be erected to place the compass upon.

Directing our attention to Plate IV, it will be perceived that the distribution of the magnetism into two polarities of opposite name separated by a neutral line, is most striking—almost as symmetrical as in a steel magnet of regular form. On the starboard side the line of neutrality extends diagonally from bow to stern; on the port side, similarly, only that it meets the keel at about two-thirds of its length; on both sides, above this line, we have south polarity, and below it north polarity, all characteristics of a ship built with her head toward the northward.

The standard compass is in the midst of south polarity, whose focus lies abaft it, and not very far distant. As the ship swings out of the meridian to the right, this pole attracts the north end of the compass needle to the left (or, which is the same thing, repels its south end to the right), so that we have the curve of deviations traced first to the westward of the central line—the case of repulsion explained in (23).

The arrows numbered 2 to 9, both inclusive, except 6

and 8, represent the direction and also (relatively among themselves) the amount of the polar force acting upon the compass; those numbered 6 and 8 represent this force with the ship heeled respectively to port and to starboard.

The two different methods of determining the magnetism acting upon the compass—namely, that by survey of the hull in dock, and from tables of deviation by swinging the ship—are thus seen to be, as they should, in perfect accord.

On examining columns 2, 4, and 5, of Table I, in connection with column 7, of Table II, we observe for the same conditions, how little the deviations on the same point differ, although determined in such widely separated places as New York, Isla Grande (near Acapulco), and San Francisco, and although they cover a period of six years, beginning with the completion of the vessel and extending through a cruise nearly around the globe, in which she was strained and shaken by many a wave, besides the periodic vibrations due to target practice with heavy guns. Truly, a hard steel magnet could scarcely show greater permanency of power.

The quadrantal components being very small (see Tables I and II), the deviation is chiefly semicircular, caused by hard iron, and vertical soft iron; and, as will be seen further on, the effect of the vertical soft iron is to that of the hard iron in the ratio of 1 to 2.3: it follows that the magnetic retentive power of the iron of which the Ranger is built is almost that of tempered steel.

For column 3 of Table I the compass was elevated (as explained in the foot-note to the table) above its usual

place, to test the effect of height; in this case it was beneficial, for it reduced the maximum deviation from 15° 51′ to 9° 43′, or 6° 08′—a very decided gain.

Column 9, of Table II, may be designated the "characteristic deviations" of the Ranger; for, being the mean of four separate determinations of those quantities at different times and places, but under similar conditions, the errors incidental to each series may be considered partly corrected or reduced. Plate II is the graphical representation of these "characteristic deviations," and to that I will now direct attention.

It illustrates forcibly a remark made in a previous part of this paper—that no matter how irregular the curve of total deviations may be, still its component parts are symmetrical. The curve of total deviation, it will be observed, swells out—is full and rounded in both the SE and SW. quadrants, whereas it is flat and has little curvature in the other two. The semicircular component is almost perfectly regular in each quarter, and has its maxima, as they should be, at east and west. The quadrantal component, likewise, is almost perfectly symmetrical, with its maxima where they should be, at the intercardinal points. Whence, then, the irregularity of their union? A glance at the Plate gives the answer most satisfactorily. In the NE. and NW. quarters the two components are on opposite sides of the central line, hence their resultant is their difference—a flattened curve on the side of the greater; in the SE. and SW. quarters, on the other hand, the components are on the same side of the central line, and so we have a full rounded curve—their sum.

Columns 6, 7, and 8, of Table II, and the graphical illustration of the total deviations of that table in Plate III, again most beautifully show how theoretical deductions are borne out by experience. The mathematical consideration of the subject requires that the heeling error should be a maximum at north and south, and a minimum near east and west. The wide separation of the curves (Plate III) due to heeling at north and south, and their approximate intersection at east and west, could scarcely be more perfect, considering the difficulties and conditions of this class of observations.

Columns 10, 11, 12, and 13 need no special explanation; they show that the Ranger has a heeling coefficient that closely approaches the maximum of this quantity for any vessel, and this might readily be inferred from the value of μ ($=+1.394$), which indicates a powerful magnetic force immediately beneath the compass, that, on swinging out of the vertical as the vessel heels, drags the needle after it.

Column 14 has been calculated merely to institute a comparison between the observed and the theoretical values of the same quantity.

The mean horizontal force λ (paragraph 35) was found from observations on two courses by means of the formula

$$\lambda=\frac{H'}{H}\,\frac{\cos\delta}{1+\mathfrak{B}.\cos\zeta-\mathfrak{C}.\sin\zeta+\mathfrak{D}.\cos 2\zeta}=0.889$$

The mean vertical force was found by the formula

$$\mu=\frac{\frac{Z'_1}{Z}.\cos\zeta_2-\frac{Z'_2}{Z}.\cos\zeta_1}{\cos\zeta_2-\cos\zeta_1}=+1.394$$

The value of the rod g (paragraph 34) was found to be

$$g=\frac{\frac{Z'_1}{Z}-\frac{Z'_2}{Z}}{\cos \vartheta_1-\cos \vartheta_2}\cdot \tan \text{Dip}=+0.015$$

The rod $a=\lambda.\mathfrak{D}-(1-\lambda)=-0.0675$, which represents magnetic induction in longitudinal soft iron (par. 26).

The rod $e=-\lambda.\mathfrak{D}-(1-\lambda)=-0.1545$, which represents magnetic induction in transverse soft iron (par. 26).

As a and e are the elements of the coefficient $\mathfrak{D}$ (par. 26), and as this is almost wholly the cause of the Ranger's quadrantal deviation (29), the two parts of $\mathfrak{D}$ are respectively: that from fore-and-aft soft iron $=-2^\circ\ 11'$ and that from athwartship soft iron $=+5^\circ\ 00'$; so that the latter is more than twice and a half the former, and both a and e are of the types that extend as continuous pieces beneath the compass (see diagrams 3 and 18 of Plate I). Indeed, the ship has iron beams, which may account for e.

From the small value of the coefficient E (Tables I and II) it may readily be inferred that the rods b, d, and h (27 and 28) are practically zero, i. e., that the Ranger has but little unsymmetrical iron acting on the compass.

Finally, it only remains to determine the parts of the coefficient $\mathfrak{B}$ (21)—the great disturber of the compass' quiet; for its helpmate, the coefficient C (24), and consequently also Q and f, which are the elements of C (24), are very feeble.

In addition to an inspection of the values of C in the Tables, it may be seen at a glance how little it contributes to B's strength, by observing that in Plate IV the direction of the polar force in all instances (except when heeled)

tends directly aft. Once listed, however, C springs into full vigor, as will be seen by the direction of the arrows 6 and 8.

The two parts of $\mathfrak{B}$ have been calculated from the formula

$$\frac{P}{\lambda} + H \, . \, \tan \mathrm{Dip} \, \frac{c}{\lambda} = B. \; H.$$

By successively using values of the dip and horizontal force at San Francisco and Acapulco, the two required values were obtained: $\frac{P}{\gamma} = -0.1064$ and $\frac{c}{\lambda} = +0.046$; whence it follows that the effect of the hard iron is two and three-tenths times greater (as previously stated) than that of the vertical soft iron. We have thus a very thorough exhibit of the magnetism of the U. S. S. Ranger, and the same may be obtained for any vessel if the necessary facilities be afforded for making the required observations.

All the observations for magnetic force, of which the results are herein given, were made at Mare Island Navy-Yard, California, by Lieut. W. P. Ray, U. S. N., navigator of the Ranger.

TABLE I.—*Summary of the deviations and magnetic*

TOTAL DEVIATIONS.

Condition of ship	Upright.	Upright.	Upright.	Upright.
Date of observation	February 1 to March 18, 1877.	March 16, 1882.	March 16, 1882.	November 18, 1882.
Place of observation	Hampton Roads and New York.	Isla Grande, Mexico.	Isla Grande, Mexico.	Acapulco, Mexico.
Latitude	37° 0′ N. 40 42 N.	17° 40′ N.	17° 40′ N.	16° 51′ N.
Longitude	76° 18′ W. 73 58 W.	101° 40′ W.	101° 40′ W.	99° 56′ W.
Name of observer	Lt. J. M. Grimes, U. S. N.	Lt. W. P. Ray, U. S. N.	Lt. W. P. Ray, U. S. N.	Lt. W. P. Ray, U. S. N.
Office index letter	"A".*	"C".†	"C" bis.‡	"D".
COLUMN 1.	COLUMN 2.	COLUMN 3.	COLUMN 4.	COLUMN 5.
Ship's head by standard compass.	Deviation.	Deviation.	Deviation.	Deviation.
North	0° 25′ east.	0° 23′ west.	3° 16′ east.	2° 16′ east.
N. by E	1 45 west.	1 06	0 41	0 06 west.
N. NE	2 00	2 15	2 53 west.	1 23
NE. by N	4 45	3 49	3 58	6 17
NE	8 45	4 52	6 34	7 14
NE. by E	10 45	6 57	9 09	9 49
E. NE	13 15	8 00	11 43	11 40
E. by N	12 55	9 04	12 47	12 24
East	14 45	9 39	13 52	14 09
E. by S	15 15	10 13	14 58	15 25
E. SE	15 30	10 18	14 03	16 17
SE. by E	15 35	9 20	14 09	16 19
SE	13 45	8 56	14 15	14 52
SE. by S	12 20	7 30	11 22	13 16
S. SE	9 15	5 04	8 29	10 08
S. by E	3 25	2 10	4 09	5 55
South	0 37 east.	0 14	0 48	2 40
S. by W	4 15	2 41 east.	4 04 east.	1 59 east.
S. SW	6 05	5 36	7 56	6 11
SW. by S	9 45	7 31	11 48	9 55
SW	12 45	8 26	13 40	12 36
SW. by W	13 30	9 21	15 03	13 47
W SW	14 15	10 17	15 28	15 23
W. by S	14 15	9 43	15 51	16 05
West	13 15	9 07	14 43	13 47
W. by N	10 15	8 32	14 17	13 59
W. NW	9 50	7 28	13 13	13 35
NW. by W	10 40	6 55	11 08	11 13
NW	9 20	4 51	9 04	9 27
NW. by N	8 10	3 18	7 30	7 39
N. NW	4 50	1 44	5 55	5 58
N. by W	2 40	0 41	3 51	3 11

* The observations at Hampton Roads include from North to W. by N., and were taken on February 21 to 26; those at New York include from W. by N. to North on March 16 and 18.

†‡ These two tables were determined to ascertain the effect of elevation on the compass: for column 3 the compass was at the extreme elevation of screw and ratchet, 9½ feet above the deck; and for column 4 it was at the ordinary elevation of 4½ feet above the deck.

All the tables of deviations of the *Ranger*, from column 2 to column 13, both inclusive, are the result of direct actual observation on every point; there are no interpolated values.

coefficients of the United States steamer Ranger (iron).

SEMICIRCULAR COMPONENTS.*

Office index letter.	"A".	"C".	"C".	"D".
Deviations analyzed by—	Lt. John Hubbard, U. S. N.	Lt. John Hubbard. U. S. N.	Lt. John Hubbard. U. S. N.	Lt. John Hubbard. U. S. N.
COLUMN 1.	COLUMN 2.	COLUMN 3.	COLUMN 4.	COLUMN 5.
North	− 0° 06′	− 0° 05′	+ 2° 02	+ 2° 28′
N. by E	− 3 00	− 1 53	− 1 42	− 1 03
N. NE	− 4 02	− 3 55	− 5 24	− 3 47
NE. by N	− 7 15	− 5 40	− 7 53	− 8 06
NE	−10 45	− 6 39	−10 07	− 9 55
NE. by E	−12 07	− 8 09	−12 06	−11 48
E. NE	−13 45	− 9 08	−13 36	−13 32
E. by N	−13 35	− 9 23	−14 19	−14 14
East	−14 00	− 9 23	−14 22	−13 58
E. by S	−12 45	− 9 23	−14 37	−14 42
E. SE	−12 40	− 8 53	−13 38	−14 56
SE. by E	−13 07	− 8 08	−12 39	−13 46
SE	−11 33	− 6 53	−11 39	−12 03
SE. by S	−10 15	− 5 24	− 9 26	−10 27
S. SE	− 7 03	− 3 24	− 7 12	− 8 03
S. by E	− 3 02	− 1 26	− 4 00	− 4 33

QUADRANTAL COMPONENTS.*

Office index letter	"A".	"C".	"C".	"D".
COLUMN 1.	COLUMN 2.	COLUMN 3.	COLUMN 4.	COLUMN 5.
North	+ 0° 38′	− 0° 01′	+ 0° 22′	− 0° 01′
N. by E	+ 1 52	+ 0 49	+ 1 22	+ 0 50
N. NE	+ 2 26	+ 1 33	+ 1 28	+ 1 52
NE. by N	+ 2 43	+ 1 32	+ 2 43	+ 2 11
NE	+ 2 06	+ 1 55	+ 3 04	+ 2 42
NE. by E	+ 1 44	+ 1 39	+ 2 37	+ 2 24
E. NE	+ 1 21	+ 1 24	+ 1 35	+ 1 58
E. by N	+ 0 32	+ 0 31	+ 0 51	+ 1 36

MAGNETIC COEFFICIENTS.*

A; 𝔄	− 0° 19′	−.0055	−0° 07′	−.0020	+ 0° 46′	+.0133	− 0° 05′	−.0014
B; 𝔅	−14 30	−.2562	−9 38	−.1698	−14 56	−.2644	−15 10	−.2683
C; ℭ	+ 0 43	+.0105	−0 21	−.0058	+ 1 17	+.0212	+ 1 52	+.0216
D; 𝔇	+ 2 27	+.0427	+1 52	+.0322	+ 2 47	+.0485	+ 2 38	+.0459
E; 𝔈	+ 0 45	+.0132	+0 05	+.0014	+ 0 13	+.0031	− 0 06	−.0017
Ship's force and "Starboard Angle"	177°	0.250	182°	.167	175°	.258	173°	.263

* The columns numbered alike, correspond; *i. e.*, the semicircular and quadrantal components and the magnetic coefficients of any one column are the separate parts of the same numbered column of the Total Deviations. The sign + denotes easterly deviation, that the *north* end of the compass needle is drawn to the eastward; the sign —, westerly deviation. By changing the signs of the given semicircular components, they become applicable to the westerly points: the given quadrantal components are also those for the SW. quadrant; and by changing their signs, they become those for the SE. and NW. quadrants.

TABLE II.—*Summary of the deviations and magnetic*

TOTAL DEVIATIONS.

Condition of ship	Heeled 6° to port.	Upright.	Heeled 6° to starboard.	Upright.
Date of observation	August 4, 1883.	August 1, 1883.	August 2 and 3, 1883.	Mean of total deviations from reports whose office index letters are "A," "C," "D," and "F" "ship's characteristic Dev."
Place of observation	San Francisco, Cal.	San Francisco, Cal.	San Francisco, Cal.	
Latitude	37° 50′ N.	37° 50′ N.	37° 50′ N.	
Longitude	122° 24′ W.	122° 24′ W.	122° 24′ W.	
Name of observer	Lt. W. P. Ray, U. S. N.	Lt. W. P. Ray, U. S. N.	Lt. W. P. Ray, U. S. N.	
Office index letter	"H".	"F".	"G".	
COLUMN 1.	COLUMN 6.	COLUMN 7.	COLUMN 8.	COLUMN 9.
Ship's head by standard compass.	Deviation.	Deviation.	Deviation.	Deviation.
North	13° 07′ east.	1° 09′ east.	8° 06′ west.	1° 46′ east.
N. by E	10 49	0 48 west.	10 33	0 29 west.
N. NE	6 10	3 15	12 26	2 23
NE. by N	2 27	5 02	14 57	5 00
N. E	1 33 west.	8 11	15 26	7 41
NE. by E	4 56	10 54	17 14	10 09
E. NE	10 12	13 03	18 01	12 25
E. by N	12 54	14 38	18 27	13 11
East	17 00	16 10	17 53	14 44
E. by S	20 07	18 18	17 57	15 59
E. SE	22 24	19 04	16 41	16 14
SE. by E	24 02	18 16	13 45	16 05
SE	24 01	16 31	12 39	14 51
SE. by S	23 08	14 46	8 56	12 56
S. SE	18 31	13 00	4 55	10 13
S. by E	16 45	8 43	0 40 east.	5 33
South	11 40	3 20	6 08	1 33
S. by W	6 00	1 26 east.	11 02	2 56 east.
S. SW	1 03	7 03	15 58	6 49
SW. by S	3 39 east.	11 09	19 01	10 39
SW	8 03	17 01	21 10	14 00
SW. by W	11 33	18 02	22 10	15 05
W. SW	14 16	18 31	22 09	15 54
W. by S	17 05	21 02	20 35	16 48
West	18 47	19 26	20 01	15 18
W. by N	19 08	19 02	16 12	14 23
W. NW	20 03	16 50	11 59	13 22
N. W. by W	20 20	15 28	9 27	12 07
N. W	19 54	13 21	5 29	10 18
N. W. by N	18 44	11 23	2 24	8 40
N. NW	16 54	9 05	0 16 west.	6 27
N. by W	15 11	4 07	4 58	3 27

coefficients of the United States steamer Ranger (iron).

SEMICIRCULAR COMPONENTS*.

Office index letter....	"H".	"F".	"G".	
Deviations analyzed by—	Lt. John Hubbard, U. S. N.	Lt. John Hubbard, U. S. N.	Lt. John Hubbard, U. S. N.	Mean from reports "A," "C," "D," and "F."
COLUMN 1.	COLUMN 6.	COLUMN 7.	COLUMN 8.	COLUMN 9.
North	+12° 24′	+ 2° 14′	− 7° 07′	+ 1° 39′
N. by E	+ 8 34	− 1 07	−10 47	− 1 43
N. NE	+ 3 37	− 5 09	−14 12	− 4 35
NE. by N	− 0 36	− 8 05	−16 59	− 7 50
NE	− 4 48	−12 36	−18 18	−10 36
NE. by E	− 8 15	−14 28	−19 42	−12 37
E. NE	−12 14	−15 47	−20 05	−14 10
E. by N	−14 59	−17 50	−19 31	−14 59
East	−17 53	−17 48	−18 57	−15 02
E. by S	−19 37	−18 40	−17 04	−15 11
E. SE	−21 24	−17 57	−14 20	−14 48
SE. by E	−22 1i	−16 52	−11 36	−14 06
SE	−21 57	−14 56	− 9 04	−12 33
SE. by S	−20 56	−13 04	− 5 40	−10 48
S. SE	−17 43	−11 03	− 2 19	− 8 20
S. by E	−15 58	− 6 25	+ 2 49	− 4 30

QUADRANTAL COMPONENTS*.

Office index letter....	"H".	"F".	"G".	"A", "C", "D", and "F".
COLUMN 1.	COLUMN 6.	COLUMN 7.	COLUMN 8.	COLUMN 9.
North	− 0° 05′	− 1° 22′	− 1 01′	− 0° 06′
N. by E	+ 1 28	− 0 01	+ 0 34	+ 0 46
N. NE	+ 1 56	+ 1 31	+ 2 03	+ 1 49
NE. by N	+ 2 27	+ 2 14	+ 2 05	+ 2 28
N. E	+ 2 39	+ 3 00	+ 3 14	+ 2 43
NE. by E	+ 2 46	+ 2 38	+ 2 52	+ 2 21
E. NE	+ 1 25	+ 2 21	+ 2 20	+ 1 49
E. by N	+ 1 26	+ 2 45	+ 1 37	+ 1 26

MAGNETIC COEFFICIENTS*.

A; 𝔄	+ 0° 40′	+.0116	+ 0° 37′	+.0107	− 0° 16′	−.0046	+ 0° 15′	+.0043
B; 𝔅	−18 15	−.3199	−18 42	−.3274	−19 03	−.3376	−15 49	−.2796
C; ℭ	+12 35	+.2103	+ 2 35	+.0458	− 6 49	−.1111	+ 1 37	+.0248
D; 𝔇	+ 2 44	+.1476	+ 2 49	+.0491	+ 3 20	+.0581	+ 2 40	+.0466
E; 𝔈	− 0 03	−.0008	− 0 55	−.0165	− 0 53	−.0154	− 0 01	−.0005
Ship's force and "Starboard Angle"	145°	0.380	172°	0.320	200°	0.350	174°	0.273

The columns numbered alike, correspond; *i. e.*, the semicircular and quadrantal components and the magnetic coefficients of any one column are the separate parts of the same numbered column of the Total Deviations. The sign + denotes easterly deviation, that the *north* end of the compass needle is drawn to the eastward; the sign —, westerly deviation. By changing the signs of the given semicircular components, they become applicable to the westerly points; the given quadrantal components are also those for the SW. quadrant; and by changing their signs they become those for the SE. and NW. quadrants.

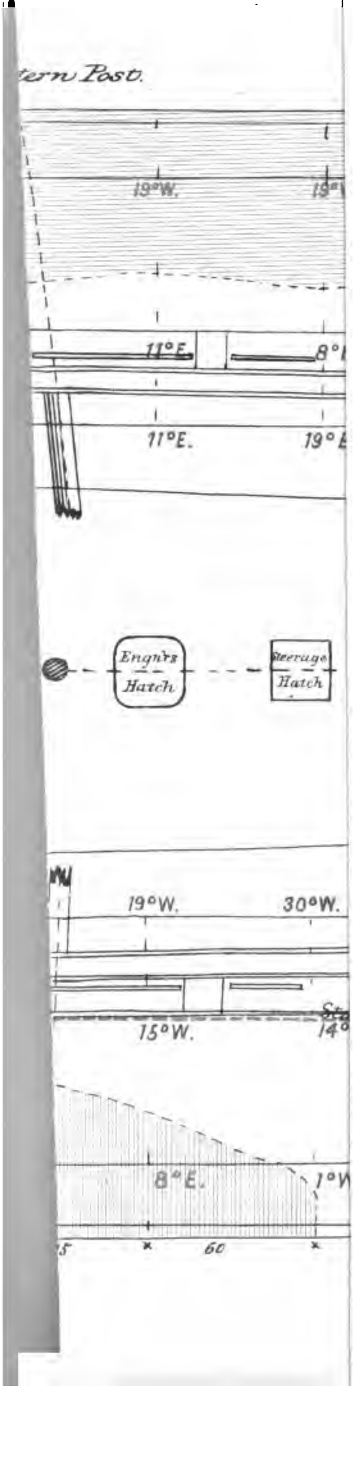
Table III.—*Summary of the deviations and magnetic coefficients of the Unit*
Steamer Ranger (iron).

	Effect of heeling 6° to port: Difference of columns 6 and 7.	Effect of heeling 6° to starboard: Difference of columns 7 and 8.	Difference in the deviations between extreme list of 6° to each side: Difference of columns 6 and 8.	"Heeling coefficient", *observed:* Each value of column 12 divided by amount of list 12°.	"Hee fici *late* cie (= sine
Office index letter	"H" and "F".	"F" and "G".	"H" and "G".		$\zeta' =$ co n
COLUMN 1.	COLUMN 10.	COLUMN 11.	COLUMN 12.	COLUMN 13.	COL
Ship's head by standard compass.					
	° ′	° ′	° ′	° ′	
North	+11 58	−9 15	21 13	1 46	
N. by E	+11 37	−9 45	21 22	1 47	
N. NE	+ 9 25	−9 11	18 36	1 33	
NE. by N	+ 7 29	−9 55	17 24	1 27	
NE	+ 6 38	−7 15	13 53	1 09	
NE. by E	+ 5 58	−6 20	12 18	1 01	
E. NE	+ 2 51	−4 58	7 49	0 39	
E. by N	+ 1 44	−3 49	5 33	0 28	
East	− 0 50	−1 43	0 53	0 04	
E. by S	− 1 49	+0 21	2 10	0 11	
E. SE	− 3 40	+2 23	6 03	0 30	
SE. by E	− 5 46	+4 31	10 17	0 51	
SE	− 7 30	+3 52	11 22	0 57	
SE. by S	− 8 22	+5 50	14 12	1 11	
S. SE	− 5 31	+8 05	13 36	1 08	
S. by E	− 8 02	+9 23	17 25	1 27	
South	− 8 20	+9 28	17 48	1 29	
S. by W	− 7 26	+9 36	17 02	1 25	
S. SW	− 8 06	+8 55	17 01	1 25	
SW. by S	− 7 30	+7 52	15 22	1 17	
SW	− 8 58	+4 09	13 07	1 06	
SW. by W	− 6 29	+4 08	10 37	0 53	
W. SW	− 4 15	+3 38	7 53	0 43	
W. by S	− 3 57	−0 27	3 30	0 17	0
West	− 0 39	+0 35	1 14	0 06	0
W. by N	+ 0 06	−2 50	2 56	0 15	0
W. NW	+ 3 13	−4 51	8 04	0 40	0
NW. by W	+ 4 52	−6 01	10 53	0 54	0
NW	+ 6 33	−7 52	14 25	1 12	1
NW. by N	+ 7 21	−8 59	16 20	1 22	1
N. NW	+ 7 49	−9 21	17 10	1 26	1
N. by W	+11 04	−9 05	20 09	1 41	1


U.S.S.

U.S.S. "Ranger."
y Yard, Cal.

N.



THE EXPERIMENTS WITH THE "SCORESBY."

Plate V represents the Scoresby, a miniature vessel made by Mr. Frank W. Cross, of the construction department of the Washington navy-yard. It is mounted for experimental purposes (see Plate VI) in the office of superintendent of compasses, room 81, of the Navy Department. Its dimensions are: Length, 6 feet 9 inches; beam, 3 feet 2 inches; height of upper deck from floor, 3 feet 2 inches. The stem, keel, and stern-post form one piece—a stout bronze casting. From the keel four heavy bronze screws rise and support the three wooden decks; the middle and lower decks may be raised and lowered at will.

The vessel is pivoted at the stern in a wooden socket screwed to the floor, and by means of a bronze wheel under the bow it may easily be turned round in a circle.

There is a contrivance for heeling the vessel to any angle up to 45°, extreme list each side, and a deep and rapid rolling motion may be communicated to it.

Thus the Scoresby, like a ship at compass buoys, may be "swung" upright or heeled, and with iron tubes and magnets suitably disposed about its decks to represent beams, smoke-stack, engines, propeller-shaft, boat-davits, masts, yards, battery, the varied disturbing effects of these upon the compass may be experimentally shown. There are several strong bronze arms for holding tubes and magnets in any position or in any direction. In Plate V these are placed in one combination of the soft-iron rods and hard-steel magnets that physically represent the mathematical theory of the deviations of the compass. And to

prove experimentally this theory was the primary object of designing the Scoresby, though this is by no means the only use to which the model has been, or may be put.

The experiments made will be found in full in the following pages; and, considering the many circumstances that both contribute to error, and to magnify those that are unavoidable—the contracted space of the room and the materials of which constructed, instrumental imperfections, close proximity of both iron and magnets to the compass, the material size of the needle and of the iron used (both of which matters are very differently regarded by theory)—the results obtained are in most close accord with theoretical values.

The iron used to represent the soft-iron rods consists of a number of pure wrought-iron tubes, each 14 inches long, 2 inches external diameter, and $1\frac{7}{8}$ inches internal diameter; they were found by experiment to be absolutely free from permanent magnetism. The compass used in all the experiments with the Scoresby, and which is seen mounted on the upper deck (Plate V), is No. 6216, a liquid compass of the ordinary $7\frac{1}{2}$-inch type. Its card is of the new form adopted by the Bureau, and is graduated to 20′ of arc. There is but one magnet, however, attached centrally on a diameter of the card, instead of the four magnets attached in chords of arcs as in the same type of compass issued to ships. This magnet is $3\frac{1}{2}$ inches long, weighs 740 grains, and consists of a bundle of fine wires of hardened steel. The pressure of the card upon the pivot in liquid is about 50 grains. For observing the meridian line traced on the north wall of the room while "swinging ship," an azimuth telescope specially

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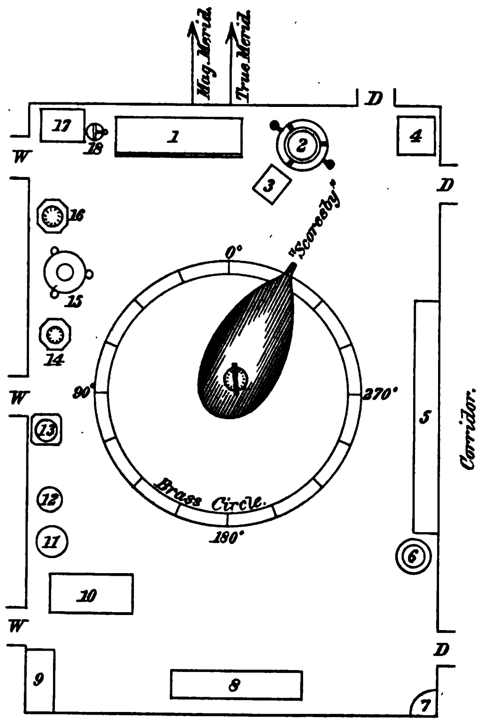
The iron used to represent the soft-iron rods consists of a number of pure wrought-iron tubes, each 14 inches long, 2 inches external diameter, and 1[illegible] inches internal diameter; they were found by experiment to be absolutely free from permanent magnetism. The compass ... the experiments with the Scoresby, and which is ... mounted on the upper deck (Plate V), is No. C?1...

... compass of the ordinary 7½-inch type. Its card ... new ... adopted by the Bureau, and is graduated to 20' ... There is but one magnet, however, attached ... on a diameter of the card, instead of the four ... attached in chords of arcs as in the same ... compass issued to ships. This magnet is 5[illegible] ... weighs 740 grains, and consists of a bundle of ... wires of hardened steel. The pressure of the card ... pivot in liquid is about 50 grains. For observing the meridian line traced on the north wall of the room ... "swinging ship," an azimuth telescope specially

PLATE VI.



Room 81: Office of Superintendent of Compasses, Bureau of Navigation, Navy Department, Washington.

Dimensions of Room: Length, 29 feet; width, 20 feet; height, 15 feet; all in clear.

Materials of which constructed, chiefly iron, brick, granite, and wood.

D. Doors.
W. Windows.
1. Table.
2. Binnacle with appliances for compensating compasses.
3. Revolving book-case.
4. Dynamo-machine (hand).
5. Case for instruments and magnetic records.
6. Globe to illustrate magnetic theories of earth.
7. U. S. monitor compass.
8. Case for instruments, magnets, and blanks.
9. Wardrobe.
10. Desk.
11. Sir William Thomson's compass.
12. Lieutenant Peichl's control compass.
13. Fox dip-circle on Gimball table.
14. Compasses: U. S. Navy types.
15. Compass-testing instrument.
16. Compasses: U. S. Navy types.
17. Chart table; magnetic charts.
18. Standard alidade, devised at Bureau

made for this purpose is used (see Plate V). It magnifies eight diameters, has cross-hairs, and a prism for reflecting up the graduation of the card, so that the meridian line, and the division of the card in coincidence with it, may be seen at once directly. Although the card is divided only to 20′, still 5′ may easily be estimated.

Previous to making any of the experiments, all the iron and magnets were removed from the Scoresby, and from its vicinity, into the far limits of the room, and left there in the same relative positions throughout the entire series. The vessel was then very carefully swung, stopping on each point ample time to let the needle come to rest before taking the bearing of the meridian line.

A table of deviations made from these readings on every point, then included both the varying parallactic angle and the influence of all iron in the room that affected the compass. Such a table was obtained first with the ship upright, and, secondly, while heeled to the side and by the amount that was subsequently used in the heeling experiments.

This first table, whether upright or heeled, was verified every day, before making an experiment, by swinging the vessel on the points to be used. Then, to ascertain the effect of either a tube or magnet, it was placed in the desired position and direction by means of one of the bronze arms, and the vessel carefully swung, resting ample time on each point or heading by disturbed compass, and the bearing of the meridian line was then observed and recorded.

A comparison of the table of deviations thus obtained with that for which neither iron nor magnet was on the vessel, gave the desired information. In this way the effect of each of the nine soft iron rods and three steel magnets described in the following experiments was obtained.

Plate VII represents the results of experiments made, to show the distinctive magnetic features an iron or steel vessel acquires by being built with her head in a particular azimuth.

For these experiments two wrought-iron plates, devoid of permanent magnetism, each 5 feet long, 2 feet 6 inches wide, and ¼ inch thick, were provided. Wooden boards of like size were also prepared. The Scoresby was successively swung into the magnetic headings South, North, NW., and SW., and blocked on each one; the wooden boards were attached to her sides in a vertical position, and thirty observations of deflection made on each side with a compass at the regular intervals indicated by the position of the figures on the plate.

The magnetic effect of the room alone for each heading of the Scoresby was thus obtained.

The iron plates were then attached in precisely the same way that the boards had been, and after resting some days in each magnetic azimuth, during which time they were frequently hammered all over with a wooden mallet, the observations for deflection were repeated at the same points. The distance of the compass from the boards and the plates was in all instances 13½ inches. This process is the one described in paragraphs (2) and (10) of this paper, for determining the location of the poles and neutral line—the

"magnetic survey" of a ship: and in the experiments with the Scoresby, a comparison of the deflections when the boards were attached with those when the plates were substituted, gave the magnetic condition of the plates alone, just as in the case of a ship in dry dock a comparison of the observations, with and without the ship, gave the effect of the latter.

In this latitude, according to theory, an iron or steel ship built head *south* (magnetic) should have blue (south) polarity pervading the upper forward body of the hull, and red (north) polarity all over the lower after body, the neutral line extending diagonally from rail aft to keel forward, and making with the horizontal an angle equal to the complement of the magnetic dip at the place where the ship was built. Any inclination of the keel to the horizontal while building will of course introduce a like change in the *direction* of the neutral line. In Experiment 1 the magnetic dip on the Scoresby was 65°; hence the neutral line should decline 25° from the horizontal; on the starboard side this is the actual inclination, and on the port side it is 24°; moreover, the polarity is in rigid conformity to theory.

In a ship built head north (magnetic), theory requires that the neutral line extend from the bow diagonally to the keel aft, with the upper after body of blue, and the lower forward body of red, polarity; and Experiment 2 demonstrates this. The plates, however, undoubtedly retained some vestige of the polarity acquired in Experiment 1, to alter the theoretical direction of the neutral line, for on the starboard side its actual inclination is 15°, and

on the port side, 17° to the horizontal, whereas in both cases it should be 22°, as the magnetic dip on the Scoresby, head north, was 68°.

If, at the same navy-yard, a series of iron ships were built with their heads on the points between north and west, according to theory it would be found: that the neutral line on each, as we progressed from the north toward the west, was gradually shifted from being a diagonal on both sides of the ship whose head was north, to a line parallel to the keel on the ship whose head was west; and that the area covered by each polarity on both sides would undergo a corresponding contraction or expansion, until, in the case of the ship head west, we would find either that all of the starboard side had red polarity and all of the port side blue, or, if both polarities existed in each side, they would appear only as a narrow band of blue beneath the rail on the starboard side with all below red, while on the port side there would be a narrow band of red just above the keel with all else blue. And the tendency to this state of affairs is clearly evident in Experiment 3; for it will be seen that the effect of building a ship NW. is to contract the area of blue on the starboard, and the area of red on the port, with a reciprocal expansion of both polarities on the two sides, and a change in the direction of the neutral line. An entirely similar tendency is apparent in Experiment 4, only, that while Experiment 3 indicates traces of its northerly origin in the changing direction of the neutral line, Experiment 4 equally shows its southern relationship—both precisely as theory requires.

From these experiments it is fair to infer that ships built in the eastern semi-circle would equally exhibit features indicative of the particular azimuth of their heads while building.

As to the direction most favorable for making a magnetic survey, a few remarks, based upon theoretical considerations which have been fully borne out by personal experience, will be offered.

The inductive action of the earth will variously alter the permanent magnetism of the hull according to the azimuth in which the ship is surveyed, but to some extent in all azimuths; so that it is never the sole effect of the magnetism of the hull that we obtain, but this somewhat modified by the particular azimuth of the head during the survey.

The best results will always be obtained with a ship lying north and south, because the disturbing force of the hull then acts at right angles to the deflected needle—a sensitive position, in which small changes are accuraturately and reliably measured.

The value of direction steadily decreases until we reach east and west, which is not only the worst, but one in which it is all but impossible to deduce any decided results, on account of the disturbing force acting in the prolongation of the needle. An approximation to this was found to be the case in the surveys of the United States Steamer Passaic (iron-clad), United States Steamer Pinta (iron tug), and British (iron) steamship Egypt, all surveyed in the Norfolk navy-yard dock, whose magnetic direction is N. 73° W. Better results have been obtained

in the New York navy-yard dock, S. 35° W. (magnetic), and in that at the Boston navy-yard, N. 29° W. (magnetic).

Experiments with the Scoresby were made, both head west and head east, as follows:

Head west (magnetic).—On February 12, 1884, the iron plates being still attached, the vessel was moved to head west (from having been north) on completing experiment 2; plates hammered at intervals until February 19, then surveyed; no decided or characteristic features—the two polarities irregularly commingled, and deflections small, on both plates.

Head west.—March 25, experiment repeated; result similar.

Head east (magnetic).—On May 28, the Scoresby was moved to head east, and the iron plates attached. In the interval, since the last experiment, March 25, they had lain in a north and south direction, but without being hammered at all. From May 28 until June 2, the plates were repeatedly tapped all over, the vessel heading east during this time. The survey was made on the latter date. It showed quite approximately what theory required—all red polarity on the port side, and all blue on the starboard; only a very small strip of blue just below the rail forward on the port side, and a small area of red on the starboard side, aft, above the keel, broke the continuity of color on each side; and in these contracted areas the deflections, though few in number, were comparatively large in amount, whereas over the large blue area of the starboard, and the like large extent of red on the port side, where the deflections were large in number, the amount in each case was very small.

The experiment, however, was sufficiently decided and satisfactory to establish the features of a ship built head east, and these were in accord with theory.

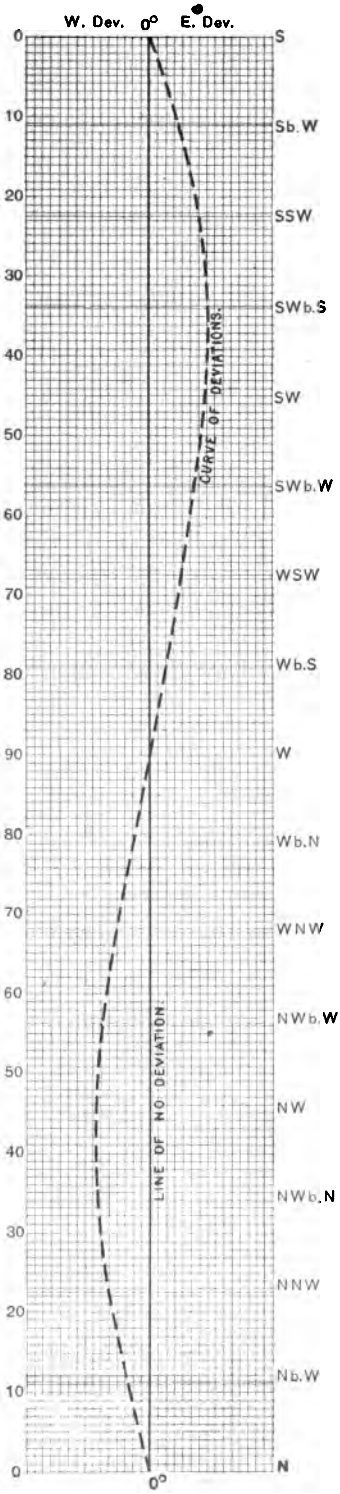
EXPERIMENT 5: PARAMETER + *a*.

[See articles 16 and 26, and position 1 of rod, in Plate 1.]

TABLE IV.

***Observations:* May 6, 1884.**

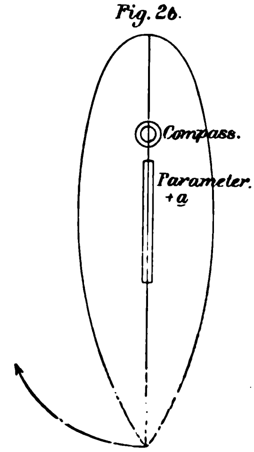
Heading of Scoresby by compass No. 6216.	Bearing of True Meridian line on wall, *without* Tube on vessel.	Bearing of True Meridian line on wall, Tube placed as in Fig. 26.	Deviations produced by Parameter + *a*
(1)	(2)	(3)	(4)
S.	N. 6° 45′ E.	N. 7° 0′ E.	0° 15′ W.
S. by W.	N. 7 30 E.	N. 4 0 E.	3 30 E.
S. SW.	N. 8 05 E.	N. 2 0 E.	6 05 E.
SW. by S.	N. 8 45 E.	N. 1 45 E.	7 0 E.
SW.	N. 9 10 E.	N. 2 30 E.	6 40 E.
SW. by W.	N. 9 40 E.	N. 4 15 E.	5 25 E.
W. SW.	N. 10 0 E.	N. 6 10 E.	3 50 E.
W. by S.	N. 10 25 E.	N. 8 30 E.	1 55 E.
W.	N. 10 40 E.	N. 10 55 E.	0 15 W.
W. by N.	N. 10 50 E.	N. 13 20 E.	2 30 W.
W. NW.	N. 10 40 E.	N. 15 0 E.	4 20 W.
NW. by W.	N. 10 30 E.	N. 16 05 E.	5 35 W.
NW.	N. 10 10 E.	N. 16 40 E.	6 30 W.
NW. by N.	N. 9 40 E.	N. 16 0 E.	6 20 W.
N. NW.	N. 9 0 E.	N. 13 10 E.	4 10 W.
N. by W.	N. 8 15 E.	N. 11 10 E.	2 55 W.
N.	N. 7 20 E.	N 7 0 E.	0 20 E.



Curve illustrating effect of Parameter + *a*. (Col. 4, Table IV.)

Each small square is 1°. Curve, natural size.

Fig. 26.

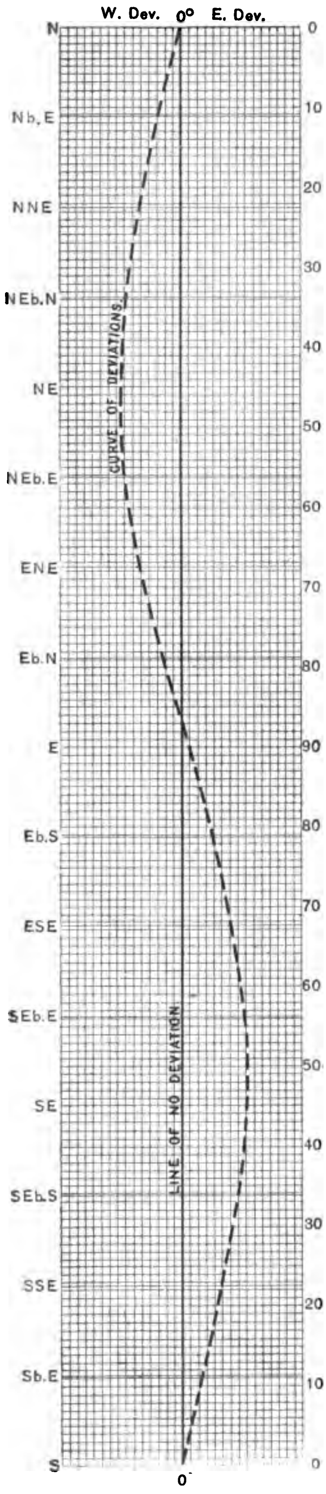


EXPERIMENT 5: PARAMETER $+a$.

Vessel upright and swung through western semicircle, resting two minutes on each point. Tube: wrought iron; length 28 in.; ext. diam. 2 in.; int. diam. $1\frac{7}{8}$ in.; weight 8 lbs. (this tube really consists of two similar and equal tubes, each 14 in. long, capable of being screwed together so as to make one tube, 28 in.); placed horizontally in vertical plane through keel, entirely forward of compass; axis in plane of compass needle; nearest end 7 in. from pivot, which, by trial, was found far enough to prevent mutual induction between tube and needle. The engines, boilers, water-tanks, &c., all soft iron, wholly forward of the compass, and whose resultant magnetic effect may be transferred into the position occupied by the parameter in Fig. 26, may be cited as bodies of which this parameter is a representative.

Theoretically, there should be no deviation at S., W., and N., and the maximum should fall at SW., instead of SW. by S; the difference from the ideal curve is slight, however, and well within the range of probable error mentioned in a previous page.

By "probable error" is not intended the technical meaning of that phrase as used in the Method of Least Squares, but such error as, from the conditions of the case, will probably occur.



Curve illustrating action of Parameter — *a*. (Col 4, Table V.)

Each small square is 1°. Curve, enlarged six times.

EXPERIMENT 6: PARAMETER — *a*.

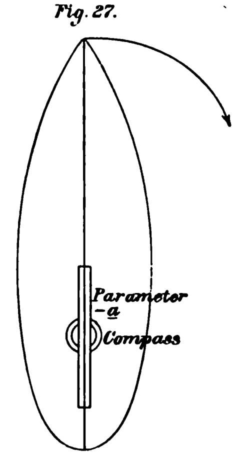
[See articles 16, 20, and 26, and position 3 of rod, Plate 1.]

TABLE V.

Observations: May 26, 1884.

Heading of Scoresby by compass No. 6216.	Bearing of True Meridian and other lines on wall, *without* Tube on vessel.	Bearing of lines designated in column 2, *with* tube placed as in Fig. 27.	Deviations produced by Parameter — *a*.
(1)	(2)	(3)	(4)
N.	N. 44° 10′ W.	N. 44° 10′. W.	0° 0′
N. by E.	N. 44 20 W.	N. 43 50 W.	0 30 W.
N. NE.	N. 5 40 E.	N. 6 25 E.	0 45 W.
NE. by N.	N. 4 55 E.	N. 5 50 E.	0 55 W.
NE.	N. 4 05 E.	N. 5 20 E.	1 15 W.
NE. by E.	N. 3 30 E.	N. 4 40 E.	1 10 W.
E. NE.	N. 3 0 E.	N. 4 0 E.	1 0 W.
E. by N.	N. 3 0 E.	N. 3 20 E.	0 20 W.
E.	N. 3 0 E.	N. 2 50 E.	0 10 E.
E. by S.	N. 3 0 E.	N. 2 20 E.	0 40 E.
E. SE.	N. 3 20 E.	N. 2 10 E.	1 10 E.
SE. by E.	N. 3 40 E.	N. 2 20 E.	1 20 E.
SE.	N. 4 10 E.	N. 2 50 E.	1 20 E.
SE. by S.	N. 4 40 E.	N. 3 30 E.	1 10 E.
S. SE.	N. 5 20 E.	N. 4 30 E.	0 50 E.
S. by E.	N. 6 0 E.	N. 5 40 E.	0 20 E.
S.	N. 38 10 W.	N. 38 10 W.	0 0

Fig. 27.

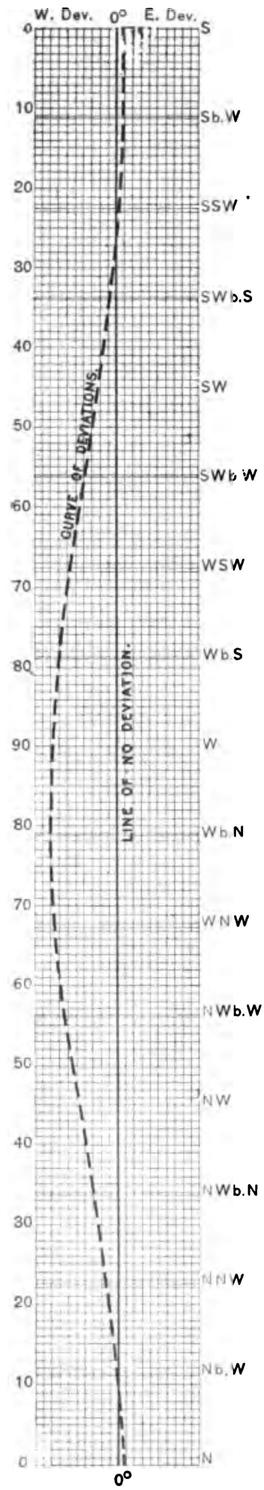


EXPERIMENT 6: PARAMETER —a.

Vessel upright and swung through eastern semicircle, resting two minutes on each point. Tube: same 28-inch one used in Experiment 5; placed horizontally in vertical plane through keel, above compass; middle point over pivot; axis 10 inches above plane of needle and parallel to that plane. The propeller shaft, or an iron keel, would be represented by the parameter placed as in Fig. 27.

The results of this experiment could scarcely be in closer accord with theory.

From the relative positions of the tube and azimuth-telescope, it was not always possible to observe the meridian line traced on the north wall of the room; so that, in this and other experiments, lines that were suitably traced on the different walls had to be observed. In the present experiment this was the case when the vessel headed N., N. by E., and S. Of course this practice in no wise affects the results.



Curve illustrating action of Parameter + *b*. (Col. 4, Table VI.)

Each small square is 1°. Curve, natural size.

Experiment 7: Parameter + *b*.

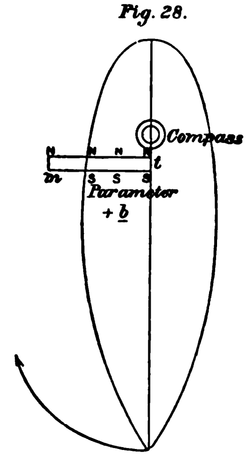
[See articles 17 and 27, and position 4 of rod, Plate 1.]

Table VI.

***Observations:* *May* 8, 1884.**

Heading of Scoresby by compass No. 6216.	Bearing of True Meridian line on wall, *without* Tube on vessel.	Bearing of True Meridian line on wall, Tube placed as in Fig. 28.	Deviations produced by Parameter $+b$.
(1)	(2)	(3)	(4)
S.	N. 6° 45′ E.	N. 6° 0′ E.	0° 45′ E.
S. by W.	N. 7 30 E.	N. 6 30 E.	1 0 E.
S. SW.	N. 8 05 E.	N. 7 20 E.	0 45 E.
SW. by S.	N. 8 45 E.	N. 9 20 E.	0 35 W.
SW.	N. 9 10 E.	N. 11 30 E.	2 20 W.
SW. by W.	N. 9 40 E.	N. 13 40 E.	4 0 W.
W. SW.	N. 10 0 E.	N. 15 40 E.	5 40 W.
W. by S.	N. 10 25 E.	N. 17 20 E.	6 55 W.
W.	N. 10 40 E.	N. 18 20 E.	7 40 W.
W. by N.	N. 10 50 E.	N. 18 45 E.	7 55 W.
W. NW.	N. 10 40 E.	N. 18 30 E.	7 50 W.
NW. by W.	N. 10 30 E.	N. 17 20 E.	6 50 W.
NW.	N. 10 10 E.	N. 15 05 E.	4 55 W.
NW. by N.	N. 9 40 E.	N. 12 50 E.	3 10 W.
N. NW.	N. 9 0 E.	N. 10 20 E.	1 20 W.
N. by W.	N. 8 15 E.	N. 8 0 E.	0 15 E.
N.	N. 7 20 E.	N. 6 35 E.	0 45 E.

Fig. 28.



Experiment 7: Parameter + *b*.

Vessel upright and swung through western semicircle, resting two minutes on each point. Tube: same 28-inch one used in Experiment 5; placed horizontally; axis in plane of needle, and at right angles to vertical section through keel; nearest point of tube 7 inches from pivot.

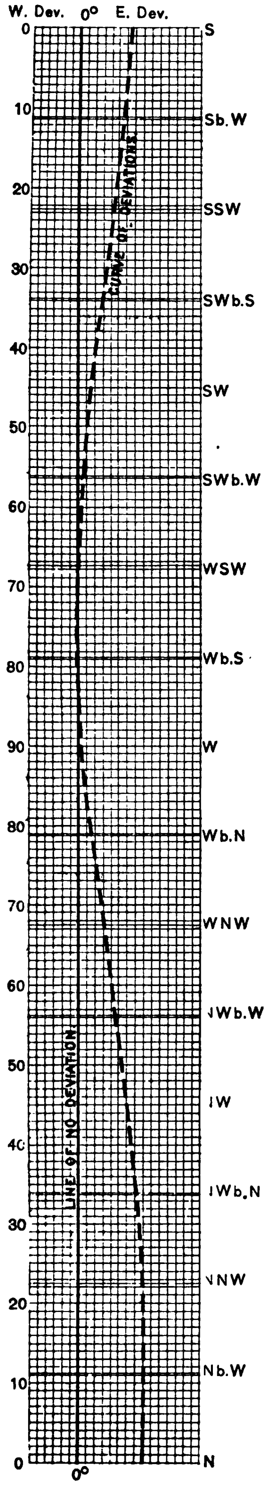
The parameter of Fig. 28 represents one phase of the action of any mass of soft iron placed on the starboard side, forward of the compass, and which has no symmetrically placed piece on the port side.

Theoretically, all the deviations should be westerly, and the maximum at west; while the observations correspond closely to this, it may be said, in explanation of the differences, that on account of the size and form of the parameter used, there *is* a trace of effective polarity in the tube even when the vessel heads north and south, and near those points, whereas there should be none, and would not if the infinitely thin magnet bar of theory were used.

With the vessel heading south all the side of the tube toward the stern has red polarity, N N N, and all toward the bow blue, S S S. The focus of the former is some little distance from the end *t* of the tube—attracts the south end of the needle—and thus produces easterly deviation. As the ship swings out of the magnetic meridian toward the westward, the earth's magnetic induction

causes a change in the distribution of the magnetism on the tube, transforming all the end *m* into a red pole, and all the end *t* into a blue, the latter repelling the south end of the needle, and thus producing westerly deviation until the ship heads north, where the conditions and phenomenon at south are repeated. The facts that the deviations in the SW. quarter are less than those in the NW., and that the maximum falls at W. by N., are easily explained.

As the vessel swings from south toward the westward, the relative directions of tube and needle constantly change in such manner that the distant pole *m* of the tube, which is a north pole, repels the north end of the needle, thus diminishing the deviations produced by the south pole *t*. This state of affairs continues until *m* comes into the prolongation of the needle, which is the case when the vessel heads W. by N. Beyond this point, and until the vessel heads north, the pole *m* is on the other side of the needle, and, therefore, aids *t* in its action; hence the difference between the deviations in the two quadrants. Drawing a series of figures like Fig. 28 on the points of the western semicircle will elucidate this.



Curve illustrating action of Parameter + *d*. (Col. 4, Table VII.)

Each small square is 1°. Curve, natural size.

EXPERIMENT 8: PARAMETER + *d*.

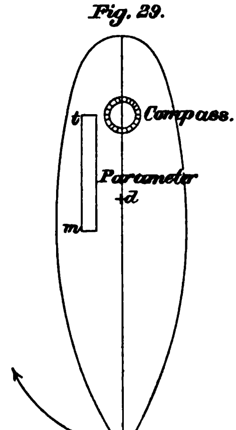
[See articles 17, 27, and 28, and position 12 of rod, Plate I.]

TABLE VII.

Observations: May 9, 1884.

Heading of Scoresby by compass No. 6216.	Bearing of True Meridian line on wall, *without* Tube on vessel.	Bearing of True Meridian line on wall, Tube placed as in Fig. 29.	Deviations produced by Parameter + *d*
(1)	(2)	(3)	(4)
S.	N. 6° 45′ E.	N. 0° 30′ E.	6° 15′ E.
S. by W.	N. 7 30 E.	N. 2 05 E.	5 25 E.
S. SW.	N. 8 05 E.	N. 3 50 E.	4 15 E.
SW. by S.	N. 8 45 E.	N. 5 50 E.	2 55 E.
SW.	N. 9 10 E.	N. 7 40 E.	1 30 E.
SW. by W.	N. 9 40 E.	N. 9 15 E.	0 25 E.
W. SW.	N. 10 0 E.	N. 10 20 E.	0 20 W.
W. by S.	N. 10 25 E.	N. 10 40 E.	0 15 W.
W.	N. 10 40 E.	N. 10 20 E.	0 20 E.
W. by N.	N. 10 50 E.	N. 9 20 E.	1 30 E.
W. NW.	N. 10 40 E.	N. 7 35 E.	3 05 E.
NW. by W.	N. 10 30 E.	N. 5 50 E.	4 40 E.
NW.	N. 10 10 E.	N. 4 0 E.	6 10 E.
NW. by N.	N. 9 40 E.	N. 2 30 E.	7 10 E.
N. NW.	N. 9 0 E.	N. 1 20 E.	7 40 E.
N. by W.	N. 8 15 E.	N. 0 45 E.	7 30 E.
N.	N. 7 20 E.	N. 0 25 E.	6 55 E.

Fig. 29.



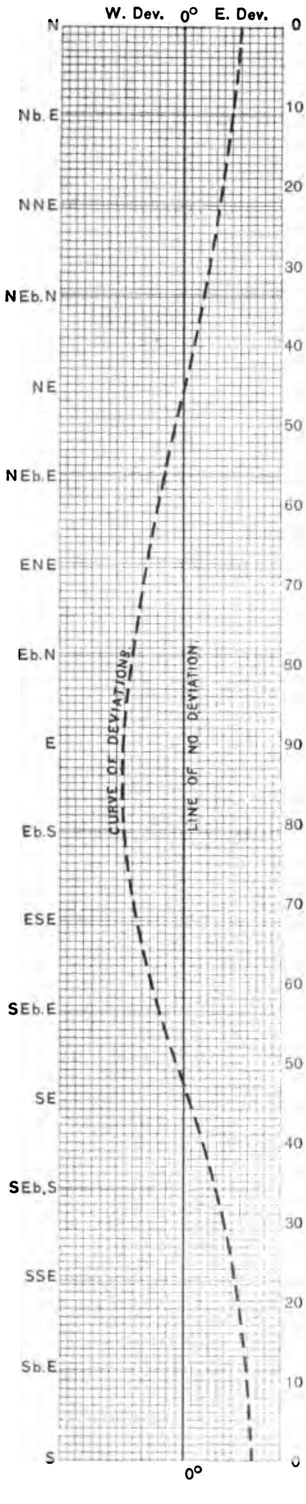
Experiment 8: Parameter + d.

Vessel upright and swung through western semicircle, resting two minutes on each point. Tube: same 28-inch one used in Experiment 5; placed horizontally, axis in plane of needle and parallel to vertical plane through keel; after-end m of tube on transverse line through pivot, nearest point of tube 7 inches from pivot. The parameter of Fig. 29 represents the second phase of the action of the mass of soft iron placed, as stated in Experiment 7, forward and to starboard of the compass.

Theoretically, the deviations in the two quadrants should be symmetrical, with maxima at north and south, and no deviation at west.

The differences are due to causes entirely analogous to those explained in the note to Experiment 7. With the vessel's head south the distant pole m diminishes the effect of t; this continues until the swinging of the ship brings m into line with the needle, which occurs near the west point. Here the earth's induction causes a new distribution of the tube's magnetism, whose action upon the needle is apparent in the irregularity of the deviation.

On the vessel continuing to swing through the northwest quarter, *both* ends of the tube conspire to produce deviation, whereas they conflicted in the southwest quarter; hence the want of symmetry.



Curve illustrating action of unsymmetrical iron: resultant of Parameters + b and + d. (Col. 4. Table VIII.)

Each small square is 1°. Curve, natural size.

EXPERIMENT 9: UNSYMMETRICAL IRON.

Resultant of Parameters $+b$ and $+d$.

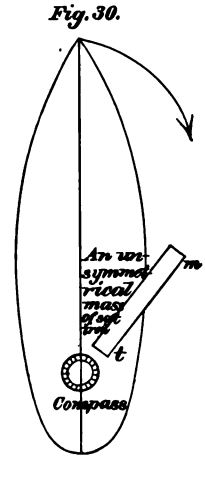
[See articles 27 and 28.]

TABLE VIII.

Observations: May 13, 1884.

Heading of Scoresby by compass No. 6216.	Bearing of True Meridian line on wall, *without* Tube on vessel.	Bearing of True Meridian line on wall, Tube placed as in Fig. 30.	Deviations produced by an unsymmetrical mass of soft iron placed as in Fig. 30.
(1)	(2)	(3)	(4)
N.	N. 7° 20′ E.	N. 0° 35′ E.	6° 45′ E.
N by E.	N. 6 20 E.	N. 0 35 E.	5 45 E.
N. NE.	N. 5 40 E.	N. 1 20 E.	4 20 E.
NE. by N.	N. 4 55 E.	N. 2 20 E.	2 35 E.
NE.	N. 4 05 E.	N. 3 50 E.	0 15 E.
NE. by E.	N. 3 30 E.	N. 5 50 E.	2 20 W.
E. NE.	N. 3 0 E.	N. 7 30 E.	4 30 W.
E. by N.	N. 3 0 E.	N. 9 10 E.	6 10 W.
E.	N. 3 0 E.	N. 10 05 E.	7 05 W.
E. by S.	N. 3 0 E.	N. 10 20 E.	7 20 W.
E. SE.	N. 3 20 E.	N. 9 20 E.	6 0 W.
SE. by E.	N. 3 40 E.	N. 7 0 E.	3 20 W.
SE.	N. 4 0 E.	N. 4 0 E.	0 0
SE. by S.	N. 4 40 E.	N. 0 50 E.	3 50 E.
S. SE.	N. 5 20 E.	N. 1 0 W.	6 20 E.
S. by E.	N. 6 0 E.	N. 1 40 W.	7 40 E.
S.	N. 6 40 E.	N. 1 10 W.	7 50 E.

Fig. 30.

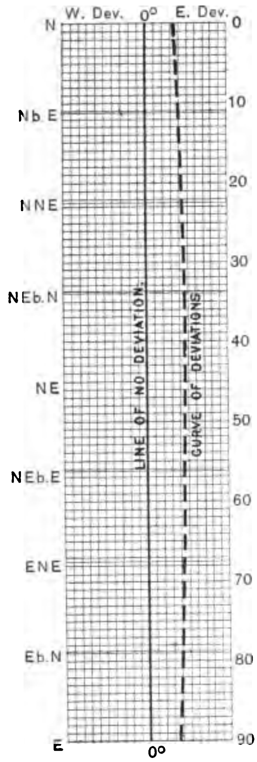


EXPERIMENT 9: UNSYMMETRICAL IRON.

Vessel upright and swung through eastern semicircle, resting two minutes on each point. Tube: same 28-inch one used in Experiment 5, and which was also used as $+b$ and as $+d$ in Experiments 7 and 8; placed horizontally, axis in plane of needle, and inclined 45° to vertical plane through keel; nearest point of tube, 7 inches from pivot.

The small deviation at NE. is but a trifling difference from the theoretical curve, and the slight want of symmetry on corresponding points is readily explicable by considering how the distant pole m affects the action of the near pole t in different parts of the semicircle. Attention is called to the reasoning of Article (28)—which was *à priori* to the experiment—and how beautifully it is borne out by this experiment and those with $+b$ and $+d$ separately. The combination, or superposition, of the two dissimilar curves of Experiments 7 and 8 could hardly be more accurately attained in practice, with each preserving its characteristic features.

Curve illustrating action of iron so placed as to produce constant deviation.
(Col. 4, Table IX.)



Each small square is 1°.
Curve, natural size.

EXPERIMENT 10: IRON PRODUCING CONSTANT DEVIATION.

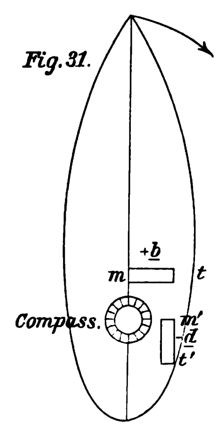
[See article 30, Parameters $+b$ and $-d$ so placed as to produce constant deviation on all points.]

TABLE IX.

Observations: May 27, 1884.

Heading of Scoresby by compass No. 6216.	Bearing of True Meridian line on wall, *without* Tubes *b* and *d* on the vessel.	Bearing of True Meridian line on wall, Tubes *b* and *d* placed as in Fig. 31.	Deviations produced by Tubes $+b$ and $-d$ placed as in Fig. 31.
(1)	(2)	(3)	(4)
N.	N. 7° 20′ E.	N. 11° 10′ E.	3° 50′ W.
N. by E.	N. 6 20 E.	N. 10 40 E.	4 20 W.
N. NE.	N. 5 40 E.	N. 10 0 E.	4 20 W.
NE. by N.	N. 4 55 E.	N. 9 40 E.	4 45 W.
NE.	N. 4 05 E.	N. 9 0 E.	4 55 W.
NE. by E.	N. 3 30 E.	N. 8 20 E.	4 50 W.
E. NE.	N. 3 0 E.	N. 7 40 E.	4 40 W.
E. by N.	N. 3 0 E.	N. 7 10 E.	4 10 W.
E.	N. 3 0 E.	N. 6 50 E.	3 50 W.

Fig. 31.

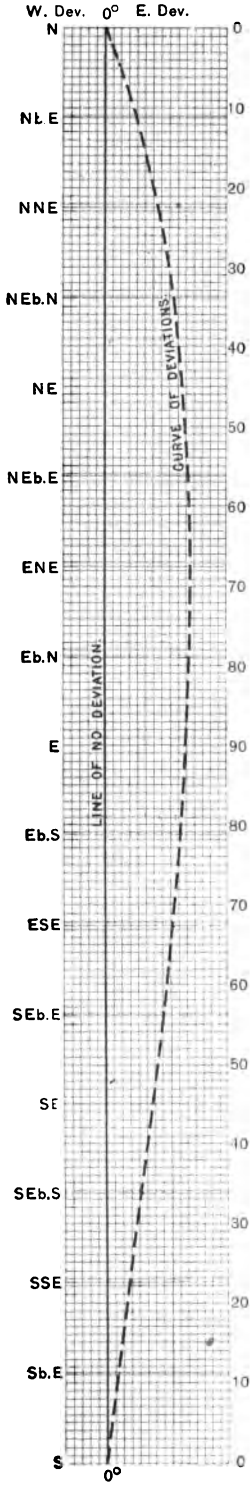


EXPERIMENT 10: IRON PRODUCING CONSTANT DEVIATION.

Vessel upright and swung through northeast quadrant, resting two minutes on each point.

The two parts (see Experiment 5) composing the 28-inch tube which was used in the experiments up to the present one, were disconnected and placed as in the figure, *i. e.*, tube $+b$ transverse to vertical plane through keel, and tube $-d$ parallel to that plane; both tubes horizontal and their axes in plane through needle; end m of b abutting on vertical plane through keel, and nearest point 7 inches fr $\acute{o}$m pivot; end m' of d abutting on transverse vertical plane through pivot, and nearest point 7 inches from pivot.

The deviations in column 4 are sufficiently uniform to prove the phenomenon desired to be established: the differences from strictly equal values may readily be ascribed to the size of the tubes, any little inequality in their form, weight, or quality, or any defect of placing them exactly symmetrical with reference to the needle.



Curve illustrating action of Parameter + c. (Col. 4, Table X.)

Each small square is 1°. Curve enlarged twice.

EXPERIMENT 11: PARAMETER + *c*.

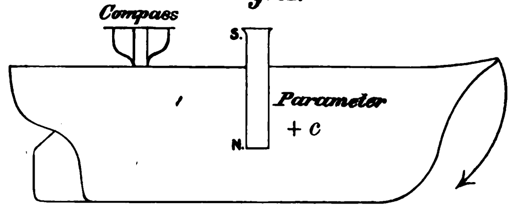
[See articles 15, 21, and 24, and position 9 of rod, Plate 1.]

TABLE X.

Observations: May 23, 1884.

Heading of Scoresby by compass No. 6216.	Bearing of True Meridian line on wall, *without* Tube on vessel.	Bearing of True Meridian line on wall, Tube placed as in Fig. 32.	Deviations produced by Parameter + *c*
(1)	(2)	(3)	(4)
N.	N. 7° 20′ E.	N. 7° 20′ E.	0° 0′
N. by E.	N. 6 20 E.	N. 4 20 E.	2 0 E.
N. NE.	N. 5 40 E.	N. 2 20 E.	3 20 E.
NE. by N.	N. 4 55 E.	N. 0 50 E.	4 05 E.
NE.	N. 4 05 E.	N. 0 40 W.	4 45 E.
NE. by E.	N. 3 30 E.	N. 1 25 W.	4 55 E.
E. NE.	N. 3 0 E.	N. 2 0 W.	5 0 E.
E. by N.	N. 3 0 E.	N. 2 10 W.	5 10 E.
E.	N. 3 0 E.	N. 1 50 W.	4 50 E.
E. by S.	N. 3 0 E.	N. 1 25 W.	4 25 E.
E. SE.	N. 3 20 E.	N. 0 50 W.	4 10 E.
SE. by E.	N. 3 40 E.	N. 0 10 E.	3 30 E.
S. E.	N. 4 0 E.	N. 1 20 E.	2 40 E.
SE. by S.	N. 4 40 E.	N. 2 30 E.	2 10 E.
S. SE.	N. 5 20 E.	N. 4 0 E.	1 20 E.
S. by E.	N. 6 0 E.	N. 5 20 E.	0 40 E.
S.	N. 6 40 E.	N. 6 50 E.	0 10 W.

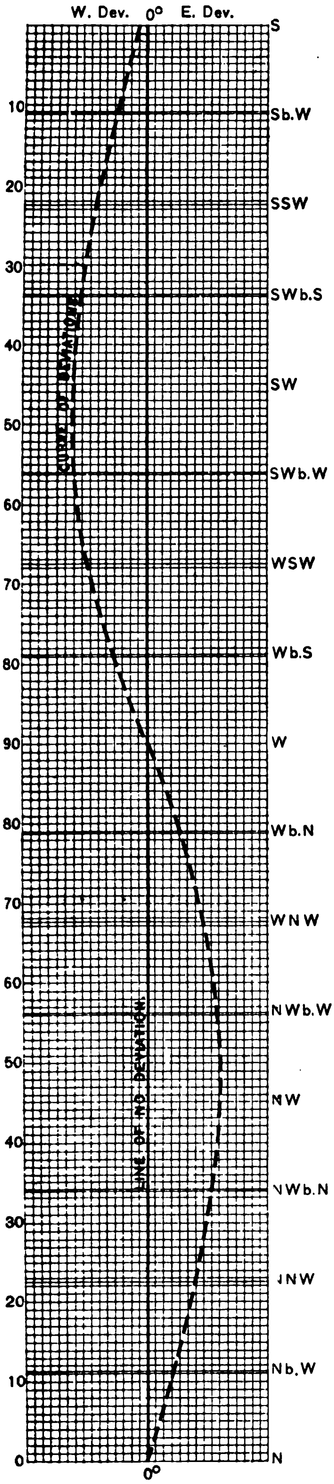
Fig. 32.



EXPERIMENT 11: PARAMETER + c.

Vessel upright and swung through eastern semicircle, resting two minutes on each point. Tube: one of the 14-inch tubes used in Experiment 10; placed forward of compass, vertically, in vertical plane through keel, upper pole in horizontal plane of needle, and nearest point of tube 10 inches from pivot. This parameter is symbolical of the smoke-stack, ventilators, stanchions—any vertical soft iron whose upper pole is near the plane of the compass needles.

The difference between the deviations on corresponding points of the two quadrants, is due to iron under the floor of the room in the part covered by the southeast quadrant, which interfered with the earth's induction; by raising the tube fourteen inches, that is, until the lower pole came into the plane of the needle, it was found that the influence of the iron in the floor almost ceased, and that the curve was nearly symmetrical. The observations in the unfavorable position are given, however, to show the identity (as stated in Article 21) of effect of the steel magnet P and that of the Parameter c.



Curve illustrating action of Parameter + e. (Col. 4. Table XI.)

Each small square is 1°. Curve enlarged twice.

EXPERIMENT 12: PARAMETER + *e*.

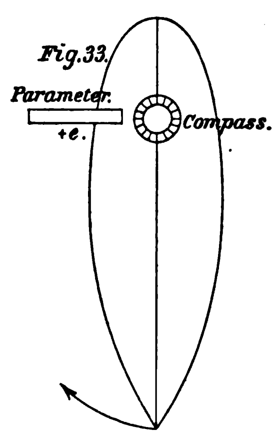
[See articles 16 and 26, and position 16 of rod, Plate 1.]

TABLE XI.

***Observations:* May 7, 1884.**

Heading of Scoresby by compass No. 6216.	Bearing of True Meridian line on wall, *without* Tube on vessel.	Bearing of True Meridian line on wall, Tube placed as in Fig. 33.	Deviations produced by Parameter + *e*
(1)	(2)	(3)	(4)
S.	N. 6° 45′ E.	N. 7° 15′ E.	0° 30′ W.
S. by W.	N. 7 30 E.	N. 9 20 E.	1 50 W.
S. SW.	N. 8 05 E.	N. 11 20 E.	3 15 W.
SW. by S.	N. 8 45 E.	N. 12 50 E.	4 05 W.
SW.	N. 9 10 E.	N. 13 50 E.	4 40 W.
SW. by W.	N. 9 40 E.	N. 14 10 E.	4 30 W.
W. SW.	N. 10 0 E.	N. 13 40 E.	3 40 W.
W. by S.	N. 10 25 E.	N. 12 20 E.	1 55 W.
W.	N. 10 40 E.	N. 10 40 E.	0 0
W. by N.	N. 10 50 E.	N. 8 40 E.	2 10 E.
W. NW.	N. 10 40 E.	N. 7 0 E.	3 40 E.
NW. by W.	N. 10 30 E.	N. 6 0 E.	4 30 E.
NW.	N. 10 10 E.	N. 5 40 E.	4 30 E.
NW. by N.	N. 9 40 E.	N. 5 45 E.	3 55 E.
N. NW.	N. 9 0 E.	N. 6 05 E.	2 55 E.
N. by W.	N. 8 15 E.	N. 6 40 E.	1 35 E.
N.	N. 7 20 E.	N. 7 20 E.	0 0

Fig. 33.



EXPERIMENT 12: PARAMETER + e.

Vessel upright and swung through western semicircle, resting two minutes on each point. Tube: the same one used in Experiment 5, that is, a 28-inch tube, made by screwing together the two 14-inch tubes of which it was originally formed; placed horizontally, axis in plane of pivot and also in plane transverse to vertical section through keel; wholly to starboard of compass as Parameter + e, and nearest point 7 inches from pivot.

The curve corresponds most beautifully to theoretical requirements.

This parameter represents a deck beam cut amidships for a hatch, or any other purpose.

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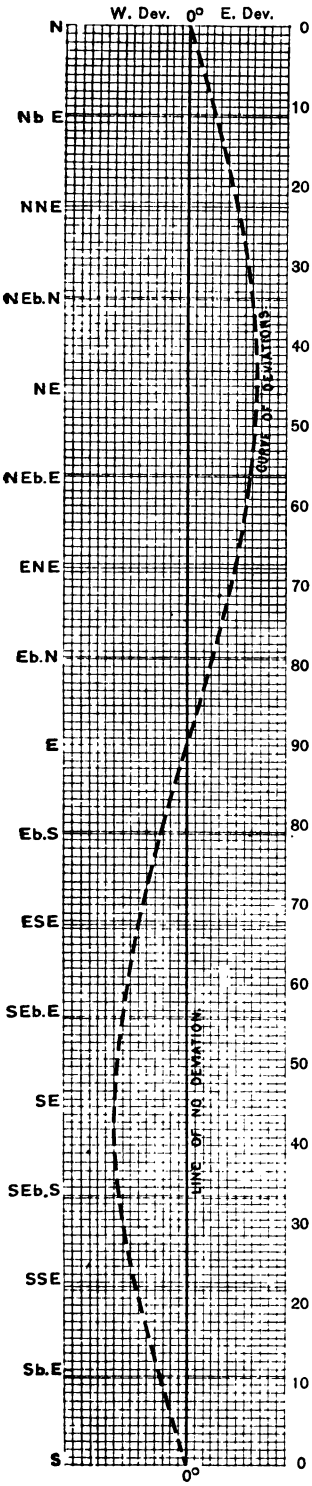
Experiment 13: Parameter —*e*.

[See articles 16 and 26, and position 18 of rod, Plate 1.]

Table XII.

Observations: May 26, 1884.

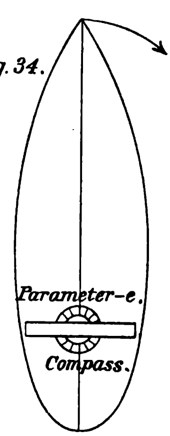
Heading of Scoresby by compass No. 6216.	Bearing of True Meridian and *other lines* on wall of room, *without* Tube on vessel.	Bearing of same lines with Tube placed as in Fig. 34.	Deviations produced by Parameter —*e*
(1)	(2)	(3)	(4)
N.	N. 7° 20′ E.	N. 7° 20′ E.	0° 0′
N. by E.	N. 6 20 E.	N. 5 50 E.	0 30 E.
N. NE.	N. 5 40 E.	N. 4 40 E.	1 0 E.
NE. by N.	N. 4 55 E.	N. 3 40 E.	1 15 E.
NE.	N. 4 05 E.	N. 2 40 E.	1 25 E.
NE. by E.	N. 3 30 E.	N. 2 20 E.	1 10 E.
E. NE.	N. 3 0 E.	N. 2 20 E.	0 40 E.
E. by N.	N. 3 0 E.	N. 2 40 E.	0 20 E.
E.	N. 42 20 W.	N. 42 20 W.	0 0
E. by S.	N 41 50 W.	N. 41 10 W.	0 40 W.
E. SE.	N. 3 20 E.	N. 4 30 E.	1 10 W.
SE. by E.	N. 3 40 E.	N. 5 0 E.	1 20 W.
SE.	N. 4 10 E.	N. 5 40 E.	1 30 W.
SE. by S.	N. 4 40 E.	N. 6 0 E.	1 20 W.
S. SE.	N. 5 20 E.	N. 6 30 E.	1 10 W.
S. by E.	N. 6 0 E.	N. 6 40 E.	0 40 W.
S.	N. 6 40 E.	N. 6 40 E.	0 0



Curve illustrating action of Parameter — *e*. (Col. 4, Table XII.)

Each small square is 1°. Curve enlarged six times.

Fig. 34.

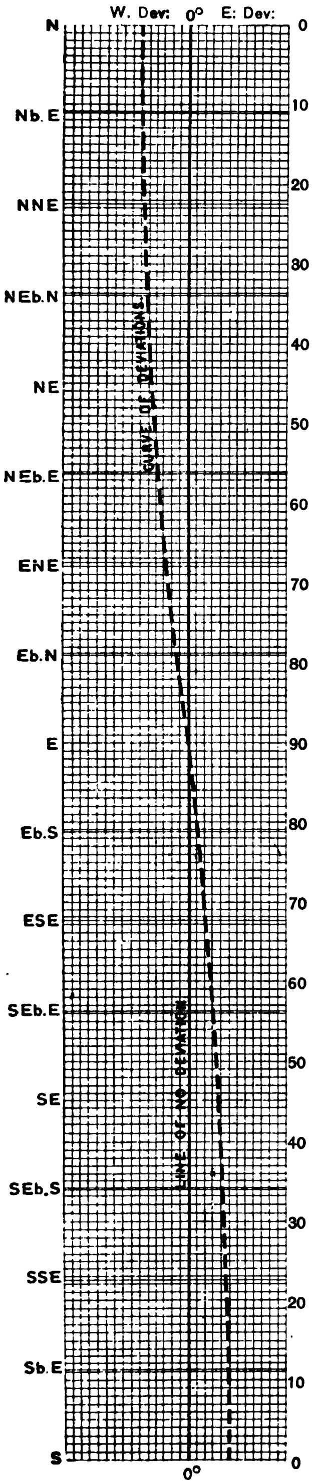


Experiment 13: Parameter $-e$.

Vessel upright and swung through eastern semicircle, resting two minutes on each point. Tube: the same one used in Experiment 5, 28 inches long; placed horizontally, at right angles to vertical plane through keel, middle point over pivot; axis of tube 11 inches above plane of needle.

As in the previous experiment, the deviations are in almost rigid conformity to theory.

This parameter represents the action of iron deck beams unbroken by hatches.



Curve illustrating effect of Parameter — *f*. (Col. 4, Table XIII.)

Each small square is 1°. Curve, natural size.

EXPERIMENT 14: PARAMETER —*f*.

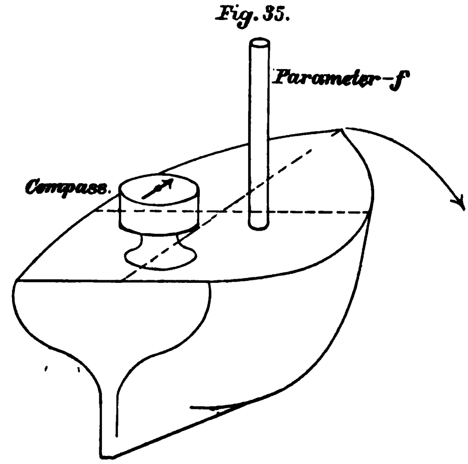
[See article 15, and position 21 of rod, Plate 1.]

TABLE XIII.

***Observations:* May 14, 1884.**

Heading of Scoresby by compass No. 6216.	Bearing of True Meridian line on wall, *without* Tube on vessel.	Bearing of True Meridian line on wall, Tube placed as in Fig. 35.	Deviations produced by Parameter —*f* placed as in Fig. 35.
(1)	(2)	(3)	(4)
N.	N. 7° 20′ E.	N. 13° 0′ E.	5° 40′ W.
N. by E.	N. 6 20 E.	N. 12 20 E.	6 0 W.
N. NE.	N. 5 40 E.	N. 11 10 E.	5 30 W.
NE. by N.	N. 4 55 E.	N. 10 0 E.	5 05 W.
NE.	N. 4 05 E.	N. 8 30 E.	4 25 W.
NE. by E.	N. 3 30 E.	N. 7 10 E.	3 40 W.
E. NE.	N. 3 0 E.	N. 5 30 E.	2 30 W.
E. by N.	N. 3 0 E.	N. 4 10 E.	1 10 W.
E.	N. 3 0 E.	N. 3 0 E.	0 0
E. by S.	N. 3 0 E.	N. 1 50 E.	1 10 E.
E. SE.	N. 3 20 E.	N. 1 10 E.	2 10 E.
SE. by E.	N. 3 40 E.	N. 0 40 E.	3 0 E.
SE.	N. 4 0 E.	N. 0 30 E.	3 30 E.
SE. by S.	N. 4 40 E.	N. 0 25 E	4 15 E.
S. SE.	N. 5 20 E.	N. 0 40 E.	4 40 E.
S. by E.	N. 6 0 E.	N. 1 10 E.	4 50 E.
S.	N. 6 40 E.	N. 1 50 E.	4 50 E.

Fig. 35.

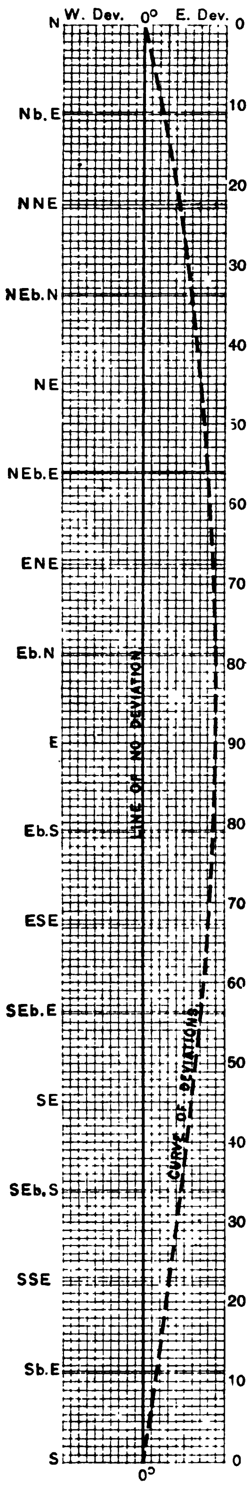


Experiment 14: Parameter $-f$.

Vessel upright and swung through eastern semicircle, resting two minutes on each point. Tube: the same one used in Experiment 5, 28 inches long; placed vertically to starboard, in transverse section through compass pivot, lower pole in plane of needle, and nearest part of tube 10 inches from pivot.

The slight difference in symmetry between the northeast and southeast branches of the curve, is due to the effect of iron in the floor in the latter quadrant.

This parameter exemplifies the effect of boat davits, diagonal bracing of ship's sides, or, generally, any vertical iron on one or both sides of the ship.



Curve illustrating effect of Steel Magnet + P. (Col. 4, Table XIV.)

Each small square is 1°. Curve, natural size.

Experiment 15: Steel magnet + P

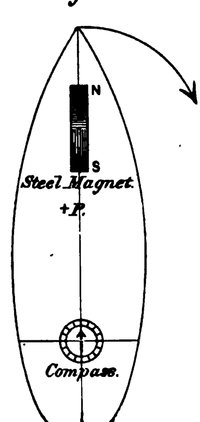
[See article 14, and position of magnet, Fig. 10.]

Table XIV.

Observations: May 20, 1884.

Heading of Scoresby by compass No. 6216.	Bearing of True Meridian line on wall, *without* magnet on vessel.	Bearing of True Meridian line on Wall, with steel magnet + P placed as in Fig. 36.	Deviations produced by steel magnet + P placed as in Fig. 36.
(1)	(2)	(3)	(4)
N.	N. 7° 20′ E.	N. 7° 20′ E.	0° 0′
N. by E.	N. 6 20 E.	N. 3 20 E.	3 0 E.
N. NE.	N. 5 40 E.	N. 1 30 E.	4 10 E.
NE. by N.	N. 4 55 E.	N. 0 50 W.	5 45 E.
NE.	N. 4 05 E.	N. 2 40 W.	6 45 E.
NE. by E.	N. 3 30 E.	N. 4 05 W.	7 35 E.
E. NE.	N. 3 0 E.	N. 5 20 W.	8 20 E.
E. by N.	N. 3 0 E.	N. 6 0 W.	9 0 E.
E.	N. 3 0 E.	N. 5 40 W.	8 40 E.
E. by S.	N. 3 0 E.	N. 5 15 W.	8 15 E.
E. SE.	N. 3 20 E.	N. 4 20 W.	7 40 E.
SE. by E.	N. 3 40 E.	N. 3 20 W.	7 0 E.
SE.	N. 4 0 E.	N. 1 30 W.	5 30 E.
SE. by S.	N. 4 40 E.	N. 0 15 E.	4 25 E.
S. SE.	N. 5 20 E.	N. 2 20 E.	3 0 E.
S. by E.	N. 6 0 E.	N. 4 30 E.	1 30 E.
S.	N. 6 40 E.	N. 6 40 E.	0 0

Fig. 36.



EXPERIMENT 15: STEEL MAGNET + P.

Vessel upright and swung through eastern semicircle, resting two minutes on each point. The steel magnet used was a solid cylindrical rod, 9½ inches long, and 1¼ inches in diameter; placed forward of compass in midship line, axis in horizontal plane through compass needle, south (blue) pole directed toward compass, and nearest point of magnet 33 inches from pivot.

The slightly larger deviations in the NE. quadrant over those in the SE, *may* possibly be accounted for by the magnetic action of the earth: as the magnet revolves through the points from N. to E., the earth acts with it—strengthens it; while in the rotation from E. to S. it acts against it, and diminishes its force. This magnet exemplifies the action of the sub-permanent magnetism of the hull, in which all the body forward of the compass has south (blue) polarity, and all abaft, north (red) polarity.

Experiment IV. Steel Magnet — Q.

Table VI

Bearing	Col. 2	Col. 3	Deviation (Col. 4)
1	2	3	4
N.	N. [illegible] E.	N. [illegible] W.	[illegible] E.
N. by E.	N. [illegible] E.	N. [illegible] W.	[illegible] E.
N.NE.	N. [illegible] E.	N. [illegible] W.	[illegible] E.
NE. by N.	N. [illegible] E.	N. [illegible] W.	[illegible] E.
NE.	N. [illegible] E.	N. [illegible] W.	[illegible] E.
NE. by E.	N. [illegible] E.	N. [illegible] W.	[illegible] E.
ENE.	N. [illegible] E.	N. [illegible] W.	[illegible] E.
E. by N.	N. [illegible] E.	N. [illegible] E.	[illegible] E.
E.	N. [illegible] E.	N. [illegible] E.	[illegible] W.
E. by S.	N. [illegible] E.	N. [illegible] E.	[illegible] W.
ESE.	N. [illegible] E.	N. [illegible] E.	[illegible] W.
SE. by E.	N. [illegible] E.	N. [illegible] E.	[illegible] W.
SE.	N. [illegible] E.	N. [illegible] E.	[illegible] W.
SE. by S.	N. [illegible] E.	N. [illegible] E.	[illegible] W.
S.SE.	N. [illegible] E.	N. [illegible] E.	[illegible] W.
S. by E.	N. [illegible] E.	N. [illegible] E.	[illegible] W.
S.	N. [illegible] E.	N. [illegible] E.	[illegible] W.

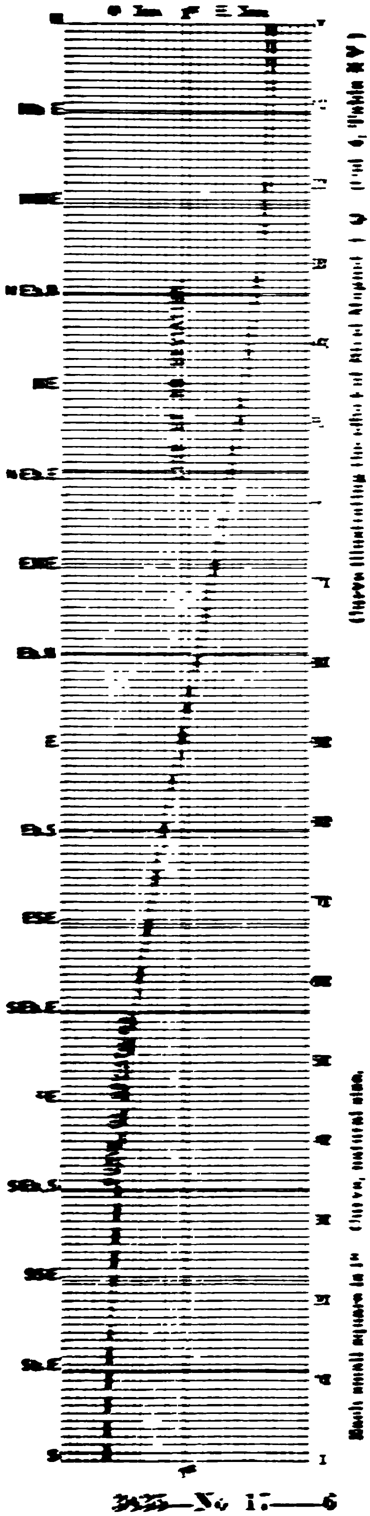
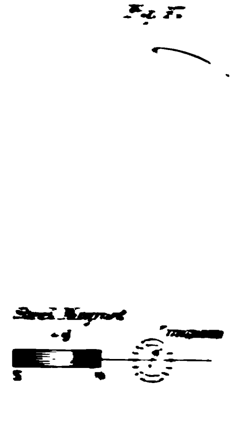


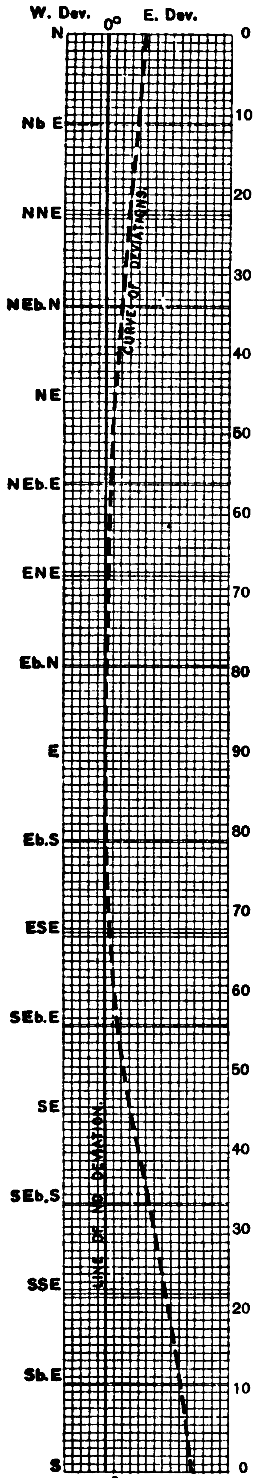
Fig. [illegible]



Experiment 16: Steel Magnet +Q.

Vessel upright and swung through eastern semicircle, resting two minutes on each point. Steel magnet, the same one used in Experiment 15; placed in transverse section through pivot on port side of compass; axis in horizontal plane of needle; north (red) pole directed toward compass, and nearest point of magnet 25 inches from pivot.

This experiment illustrates the action of the permanent magnetism of the hull when north (red) polarity pervades the port side of the ship, and south (blue) polarity, the starboard side.



Curve illustrating effect of Parameter — *g*. (Col. 4, Table XVI.)

Each small square is 1°. Curve enlarged six times.

Experiment 17: Parameter — *g*.

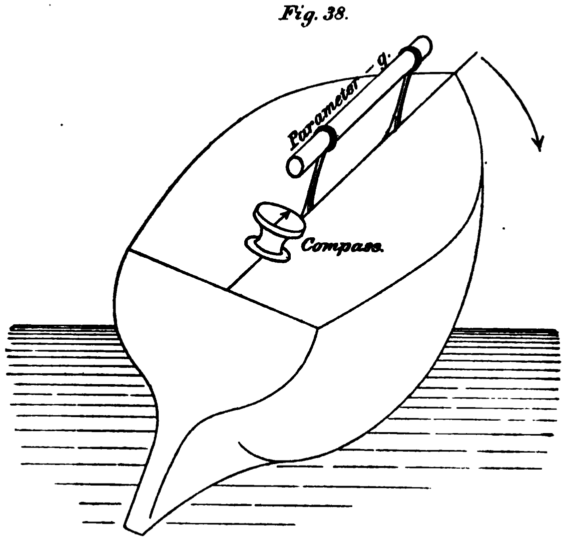
[See article 35 and position 29 of Parameter, Plate 1.]

Table XVI.

Observations: *May* 15, 1884.

Heading of Scoresby by compass No. 6211.	Bearing of True Meridian and other lines traced on walls of room, *without* Tube *g* in place.	Bearing of True Meridian and other lines on walls of room, Parameter — *g* placed as in Fig. 38.	Deviations produced by Parameter — *g* placed as in Fig. 38.
(1)	(2)	(3)	(4)
N.	N. 47° 00′ W.	N. 47° 45′ W.	0° 45 E.
N. by E.	N. 46 45 W.	N. 47 15 W.	0 30 E.
N. NE.	N. 46 15 W.	N. 46 45 W.	0 30 E.
NE. by N.	N. 45 45 W.	N. 45 45 W.	0 0
NE.	N. 45 0 W.	N. 45 0 W.	0 0
NE. by E.	N. 0 0 E.	N. 0 15 E.	0 15 W.
E. NE.	N. 0 15 E.	N. 0 45 E.	0 30 W.
E. by N.	N. 1 00 E.	N. 1 15 E.	0 15 W.
E.	N. 1 30 E.	N. 1 45 E.	0 15 W.
E. by S.	N. 2 15 E.	N. 2 30 E.	0 15 W.
E. SE.	N. 37 30 E.	N. 37 15 E.	0 15 E.
SE. by E.	N. 37 30 E.	N. 37 15 E.	0 15 E.
SE.	N. 37 45 E.	N. 36 30 E.	1 15 E.
SE. by S.	N. 46 0 E.	N. 45 15 E.	0 45 E.
S. SE.	S. 34 45 E.	S. 36 0 E.	1 15 E.
S. by E.	S. 35 45 E.	S. 37 30 E.	1 45 E.
S.	S. 36 15 E.	S. 38 0 E.	1 45 E.

Fig. 38.



EXPERIMENT 17: PARAMETER — g.

The vessel was heeled 20° to starboard during the observations of columns (2) and (3) Table XVI, and swung through the eastern semicircle, resting two minutes on each point.

Tube: the same one used in Experiment 5, 28 inches long; placed (as in Fig. 38), its axis in the longitudinal section through keel and parallel to the keel; above plane of card, forward of compass, and nearest end 13 inches from pivot.

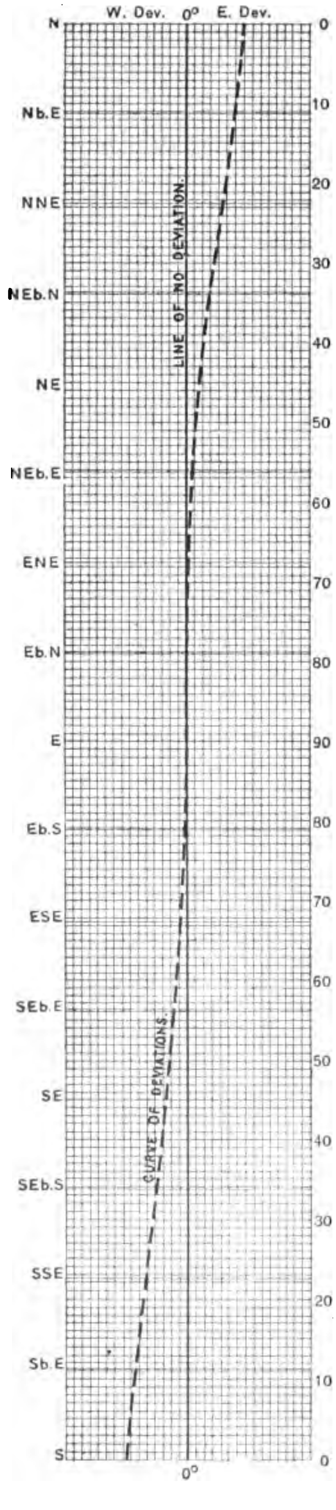
The maximum charge of induced magnetism in the tube and its maximum leverage occur when the vessel heads either north or south.

With the vessel heading south heeled to starboard, and the tube above and forward of the compass, the end nearest the compass has north (red) polarity, and its effect upon the needle is to repel the north end to the high side of the vessel, thus producing easterly deviation. (If, under similar circumstances, the tube were below, the north end of the needle would be repelled to the low side.) As the vessel swings into the SE. quadrant, both the magnetic induction in the tube and its leverage, gradually decrease and become a minimum at east; as the vessel continues to swing into the NE. quadrant, the induced magnetism in the tube is reversed, and now tends to draw the north end of the needle to the low side, when the tube is above

and forward, and to the high side when below, the effect in both cases gradually increasing to a maximum at north.

In the observations of Table XVI, this general phenomenon is evident; the irregularities and discrepancies are due to instrumental and other unavoidable errors, the smallness of the quantities to be measured, and the difficulties of making the observations.

In this and Experiments 18, 19, and 20, the compass used on the Scoresby was not the one of the previous experiments which had been specially designed for this work, but one of the new four-needle type of 7½-inch standard compass recently introduced into the Navy; a short description of it will be found in Experiment 21. The parameter g represents the effect of an iron keel when the vessel is heeled.



Curve illustrating effect of Parameter + *h*. (Col. 4, Table XVII.)

Each small square is 1°. Curve enlarged six times.

EXPERIMENT 18: PARAMETER + *h*.

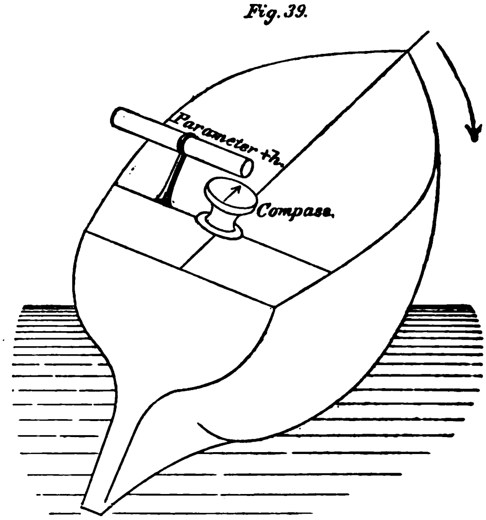
[See article 34 and position 25 of Parameter, Plate 1.]

TABLE XVII.

Observations: *May* 16, 1884.

Heading of Scoresby by compass No. 6211.	Bearing of True Meridian and other lines traced on walls of room *without* Tube *h* in place.	Bearing of True Meridian and other lines on walls of room. Parameter + *h*, placed as in Fig. 39.	Deviations produced by Parameter + *h*, placed as in Fig. 39.
(1)	(2)	(3)	(4)
N.	N. 47° 0′ W.	N. 48° 15′ W.	1° 15′ E.
N. by E.	N. 46 45 W.	N. 47 45 W.	1 0 E.
N. NE.	N. 46 15 W.	N. 47 0 W.	0 45 E.
NE. by N.	N. 45 45 W.	N. 46 15 W.	0 30 E.
NE.	N. 0 15 W.	N. 0 30 W.	0 15 E.
NE. by E.	N. 0 0 W.	N. 0 15 W.	0 15 E.
E. NE.	N. 0 15 E.	N. 0 0 W.	0 15 E.
E. by N.	N. 1 0 E.	N. 0 45 E.	0 15 E.
E.	N. 42 0 W.	N 42 0 W.	0 0
E. by S.	N. 2 15 E.	N. 2 15 E.	0 0
E. SE.	N. 37 0 E.	N. 37 15 E.	0 15 W.
SE. by E.	N. 3 45 E.	N. 4 0 E.	0 15 W.
SE.	N. 37 45 E.	N. 38 0 E.	0 15 W.
SE. by S.	N. 46 0 E.	N. 46 15 E.	0 15 W.
S. SE.	S. 34 45 E.	S. 34 0 E.	0 45 W.
S. by E.	S. 35 45 E.	S. 34 45 E.	1 0 W.
S.	S. 36 15 E.	S. 35 0 E.	1 15 W.

Fig. 39.



Experiment 18: Parameter $+h$.

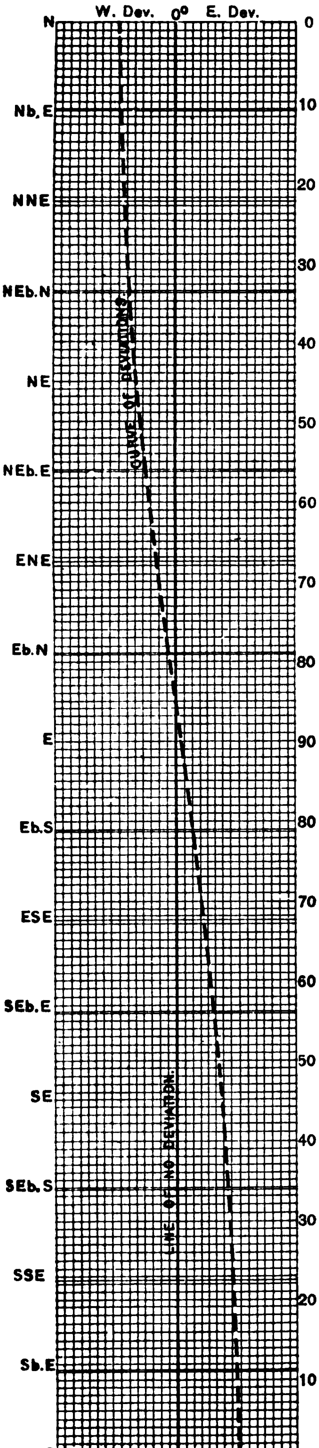
Vessel heeled 20° to starboard during the experiment, and swung through eastern semicircle, resting two minutes on each point. Tube: the same one used in Experiment 5, 28 inches long; placed as in Fig. 39, its axis in the section transverse to the keel through compass pivot; parallel to the plane of deck; above and on port side of compass, the nearest end being thirteen (13) inches from the pivot of the compass.

With the vessel heeled the parameter will be affected by vertical induction, the lower part becoming a north (red) pole, and the upper, a south (blue) pole.

When the ship's head is north, the neutral line will cut the parameter in a horizontal plane, making a certain angle with the axis of the tube; the leverage of the magnetism will be a maximum, and the needle will be repelled to the eastward. As the ship swings into the NE. quarter, the leverage becomes gradually less, and the parameter approaches (in this latitude) a plane at right angles to the line of magnetic dip, while at the same time the position of its neutral line has slowly changed, until, when the ship's head is east, the direction of the parameter nearly coincides with a plane transverse to the dip, and the new distribution of the magnetism is north (red) all over the under half of the tube, and south (blue) all

over the upper half, the neutral plane cutting the axis in its length. In this position, whatever polarity exists, will produce no deviation, since the direction of its action is in the prolongation of the needle.

The ship continuing to swing into the SE. quarter, a distribution of the magnetism similar to that while in the NE. quarter, occurs. From east to south the north end of the needle will be forced to the westward by the lower end of the parameter, which we have seen becomes a north pole, and the deviation reaches a maximum when the ship's head is south. Thus it will be seen that, under the given circumstances, the needle is always repelled to the low side of the vessel, and the observations are in strict accord with theory. Were the parameter h below the compass, it would represent the effect of a deck-beam broken by a hatch-way.



Curve illustrating action of Parameter $+k$. (Col. 4, Table XVIII.)

Each small square is 1°. Curve enlarged twice.

EXPERIMENT 19: PARAMETER $+k$.

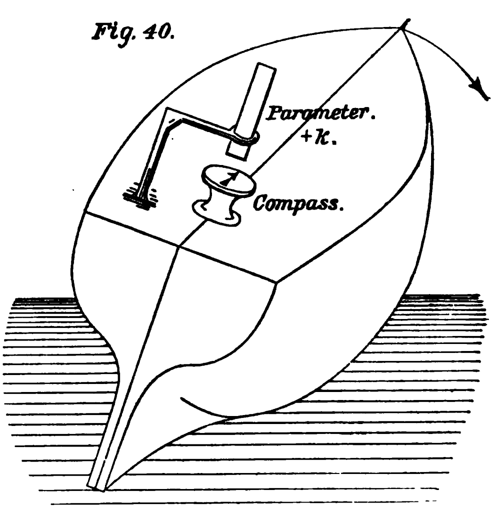
[See article 34 and position 27 of parameter, Plate 1.]

TABLE XVIII.

Observations: *May* 21, 1884.

Heading of Scoresby. by compass No. 7860.	Bearing of True Meridian and other lines on walls of room, *without* Tube k in place.	Bearing of True Meridian and other lines on walls of room, Parameter $+k$ placed as in Fig. 40.	Deviations produced by Parameter $+k$ placed as in Fig. 40.
(1)	(2)	(3)	(4)
N.	N. 1° 30′ E.	N. 5° 0′ E.	3° 30′ W.
N. by E.	N. 41 15 E.	N. 44 15 E.	3 0 W.
N. NE.	N. 40 15 E.	N. 43 15 E.	3 0 W.
NE. by N.	N. 39 15 E.	N. 42 0 E.	2 45 W.
NE.	N. 38 15 E.	N. 40 45 E.	2 30 W.
NE. by E.	S. 62 0 W.	S. 63 45 W.	1 45 W.
E. NE.	S. 63 0 W.	S. 64 0 W.	1 0 W.
E. by N.	S. 24 45 E.	S. 24 0 E.	0 45 W.
E.	S. 25 30 E.	S. 25 45 E.	0 15 E.
E. by S.	S. 27 0 E.	S. 28 0 E.	1 0 E.
E. SE.	S. 28 15 E.	S. 30 0 E.	1 45 E.
SE. by E.	N. 40 0 W.	N. 42 0 W.	2 0 E.
SE.	S. 31 30 E.	S. 34 30 E.	3 0 E.
SE. by S.	S. 61 45 W.	S. 58 45 W.	3 0 E.
S. SE.	S. 60 15 W.	S. 57 0 W.	3 15 E.
S. by E.	S. 58 45 W.	S. 55 30 W.	3 15 E.
S.	S. 57 15 W.	S. 53 30 W.	3 45 E.

Fig. 40.

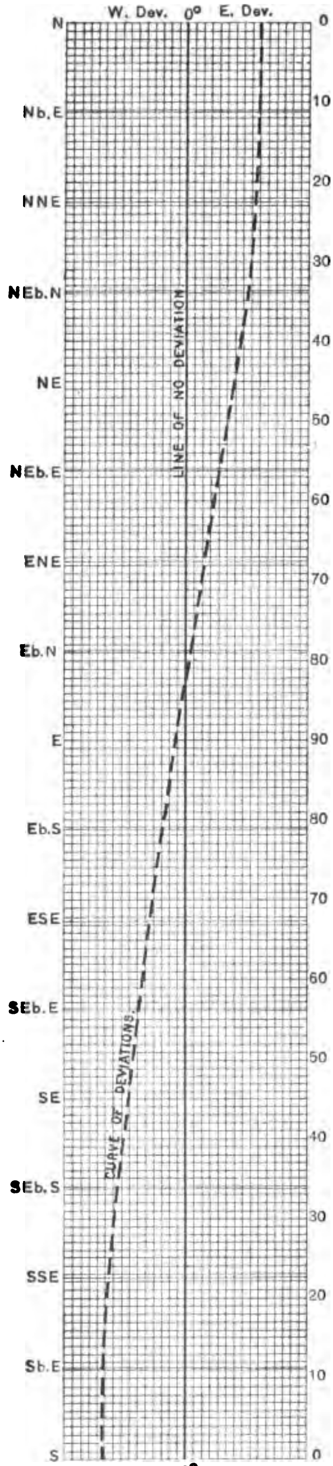


Experiment 19: Parameter $+k$.

Vessel heeled 20° to starboard during experiment, and swung through eastern semicircle, resting two minutes on each point. Tube: the same one used in Experiment 5, 28 inches long; placed as in Fig. 40, entirely above compass; axis of tube in prolongation of axis of compass; nearest end of tube, 13 inches from pivot of compass.

In this case the parameter becomes magnetized by vertical induction, the lower end being a north (red) pole, and the upper, a south (blue) pole, and the maximum leverage occurs with the ship's head north or south, gradually decreasing to zero at east and west. When the ship's head is north the lower pole of the parameter is thrown, by the heeling, to the eastward of the needle, and, being a north pole, it repels the north end of the needle, thus producing westerly deviation. This continues, with gradually decreasing effect, as the ship swings through the NE. quarter, until she heads east, when the parameter, being in a plane through the needle, its effect is zero. The vessel continuing to swing through the SE. quarter, the lower end of the parameter passes on the other (westward) side of the needle, and again repels its north end, this time producing easterly deviation, which gradually increases until it attains a maximum at south. The curve of observations is almost perfectly symmetrical.

Were *k* below the compass, its south (blue) pole would act upon the needle, and, by heeling, it would be thrown on the opposite side in each quadrant to what it is in the present case, and attract the north end of the needle; thus, in both instances, causing deviation to the high side. The Parameter $-k$ would cause deviation to the low side.



Curve illustrating effect of Magnet *R.* (Col. 4, Table XIX.)

Each small square is 1°. Curve enlarged twice.

EXPERIMENT 20: MAGNET R.

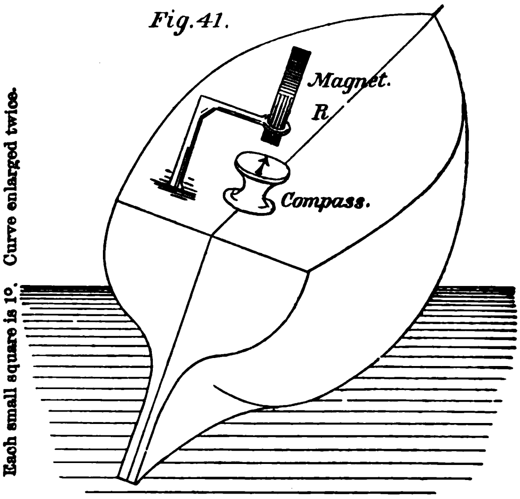
[See articles 14 and 34, and position of magnet, Fig. 10.]

TABLE XIX.

Observations: May 22, 1884.

Heading of Scoresby by compass No. 7860.	Bearing of True Meridian and other lines on walls of room *without* Magnet R in place.	Bearing of True Meridian and other lines on walls of room with Magnet R placed as in Fig. 41.	Deviations produced by Magnet R, placed as in Fig. 41.
(1)	(2)	(3)	(4)
North.	N. 1° 30′ E.	N. 3° 0′ W.	4° 30′ E.
N. by E.	N. 41 15 E.	N. 37 0 E.	4 15 E.
N. NE.	N. 40 15 E.	N. 36 0 E.	4 15 E.
NE. by N.	N. 39 15 E.	N. 35 30 E.	3 45 E.
NE.	N. 38 15 E.	N. 35 30 E.	2 45 E.
NE. by E.	S. 62 0 W.	S. 60 15 W.	1 45 E.
E. NE.	S. 63 0 W.	S. 62 0 W.	1 0 E.
E. by N.	S. 24 45 E.	S. 25 0 E.	0 15 E.
East.	S. 25 30 E.	S. 25 15 E.	0 15 W.
E. by S.	S. 27 0 E.	S. 25 30 E.	1 30 W.
E. SE.	S. 28 15 E.	S. 26 0 E.	2 15 W.
SE. by E.	N. 40 0 W.	N. 37 30 W.	2 30 W.
SE.	S. 31 30 E.	S. 28 0 E.	3 30 W.
SE. by S.	S. 61 45 W.	S. 66 0 W.	4 15 W.
S. SE.	S. 60 15 W.	S. 65 15 W.	5 0 W.
S. by E.	S. 58 45 W.	S. 64 0 W.	5 15 W.
South.	S. 57 15 W.	S. 62 30 W.	5 15 W.

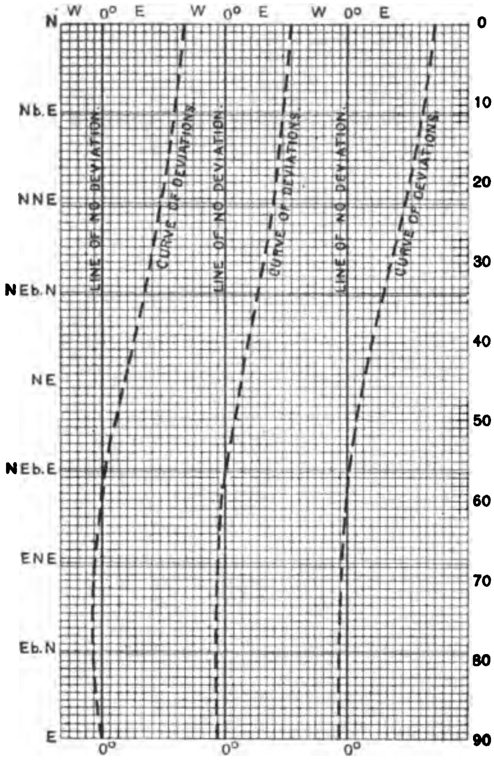
Fig. 41.



Experiment 20: Magnet R.

Vessel heeled 20° to starboard during the experiment and swung through eastern semicircle, resting two minutes on each point. Magnet, a short tube which had been rendered a permanent weak magnet, by means of an electric current, several months previously; placed entirely above the compass, axis of magnet coincident with the prolongation of the axis of the compass; south pole nearest compass and 6 inches from it. The difference in the deviations on corresponding points in the two quadrants is probably due to a want of exact coincidence of the axis of the magnet with the axis of the compass. It will be observed that the needle is drawn to the low side in both quadrants; were the magnet below the compass, south pole uppermost, the needle would be drawn to the high side in both quadrants, and the magnet in this case would represent the action of the permanent magnetism of the hull of a vessel whose after body was pervaded by south (blue) polarity, and forward body, by north (red) polarity—the characteristic features of a ship built head north, magnetic.

Curves illustrating Experiment 21.
(Cols. 4, 7, and 10, Table XX.)



Compass No. 6216. Compass No. 7860. Compass No. 3314.

Each small square is 1°.
Curve enlarged four times.

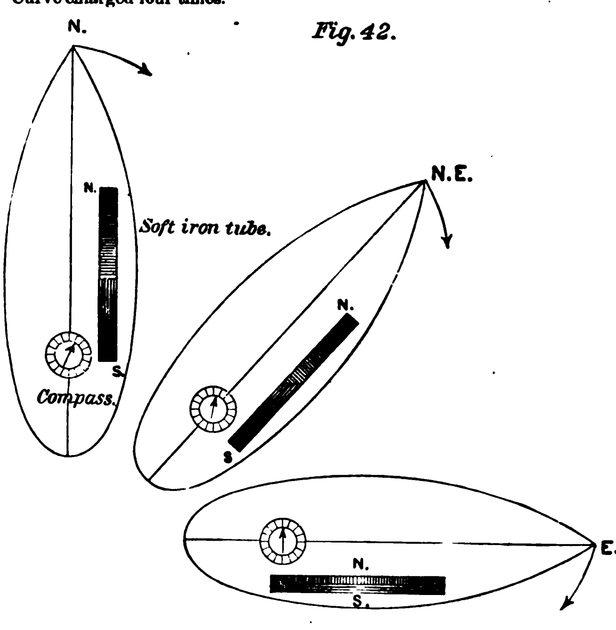


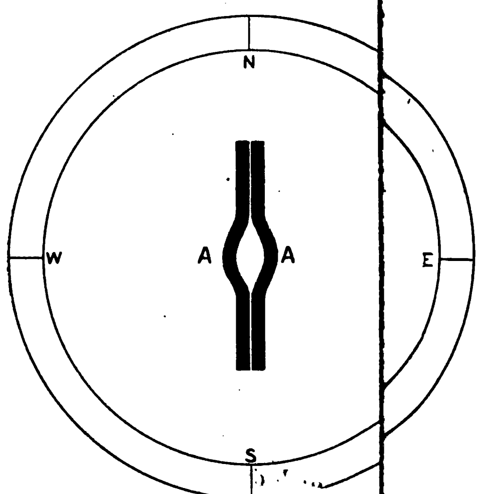
Fig. 42.

EXPERIMENT 21: *To deter-*
of compass, under the same

TABLE XX.—*Observa*

Heading of Scoresby by compass.	Bearing of True Meridian line on wall by compass No. 6216, *without* tube on Scoresby.	Bearing of True Meridian line on wall by compass No. 6216, with tube placed as in Fig. 42.
(1)	(2)	(3)
N.	N. 7° 20′ E.	N. 4° 50′ E.
N. by E.	N. 6 20 E.	N. 4 20 E.
N. NE.	N. 5 40 E.	N. 3 50 E.
NE. by N.	N. 4 55 E.	N. 3 30 E.
NE.	N. 4 05 E.	N. 3 30 E.
NE. by E.	N. 3 30 E.	N. 3 20 E.
E. NE.	N. 3 0 E.	N. 3 20 E.
E. by N.	N. 3 0 E.	N. 3 20 E.
E.	N. 3 0 E.	N. 3 0 E.

Fig. 1



LIQUID COMPASS No. 6216.

7½-inch card.

A A—two bundles of needles placed close togethe[illegible]n each bundle; to constitute but one, attached to the card in a d[illegible] of magnetized each bundle, 3½ inches; weight, 370 grains; total w[illegible] of 30° on each steel, 740 grains. Each bundle is composed of [illegible]rd and steering wires of about the thickness of a fine knitting [illegible]ntroduction, in compass previously referred to as having been sp[illegible] experimental work on the Scoresby.

mine what difference (if any) occurs in the deviations of different types circumstances, when subjected to the influence of soft iron alone.

tions: May 23, 1884.

Deviations of compass No. 6216 produced by tube placed as in Fig. 42.	Bearing of True Meridian line on wall by compass No. 7860, *without* tube on Scoresby.	Bearing of True Meridian line on wall by compass No. 7860, with tube placed as in Fig. 42.	Deviations of compass No. 7860 produced by tube placed as in Fig. 42	Bearing of True Meridian line on wall by compass No. 3314, *without* tube on Scoresby.	Bearing of True Meridian line on wall by compass No. 3314, with tube placed as in Fig. 42.	Deviations of compass No. 3314 produced by tube placed as in Fig. 42.
(4)	(5)	(6)	(7)	(8)	(9)	(10)
2° 30′ E.	N. 7° 10′ E.	N. 5° 10′ E.	2° 0′ E.	N. 7° 35′ E.	N. 4° 45′ E.	2° 50′ E.
2 0 E.	N. 6 30 E.	N. 4 45 E.	1 45 E.	N. 6 45 E.	N. 4 20 E.	2 25 E.
1 50 E.	N. 5 55 E.	N. 4 30 E.	1 25 E.	N. 5 55 E.	N. 4 0 E.	1 55 E.
1 25 E.	N. 5 0 E.	N. 4 10 E.	0 50 E.	N. 5 10 E.	N. 4 0 E.	1 10 E.
0 35 E.	N. 4 30 E.	N. 4 0 E.	0 30 E.	N. 4 30 E.	N. 3 55 E.	0 35 E.
0 10 E.	N. 4 0 E.	N. 3 50 E.	0 10 E.	N. 4 0 E.	N. 4 0 E.	0 0
0 20 W.	N. 3 30 E.	N. 3 40 E.	0 10 W.	N. 3 30 E.	N. 3 40 E.	0 10 W.
0 20 W.	N. 3 10 E.	N. 3 30 E.	0 20 W.	N. 3 20 E.	N. 3 35 E.	0 15 W.
0 0	N. 3 0 E.	N. 3 15 E.	0 15 W.	N. 3 0 E.	N. 3 15 E.	0 15 W.

EXPERIMENT 21: *Deviations of different types of compass under the same conditions of soft iron.*

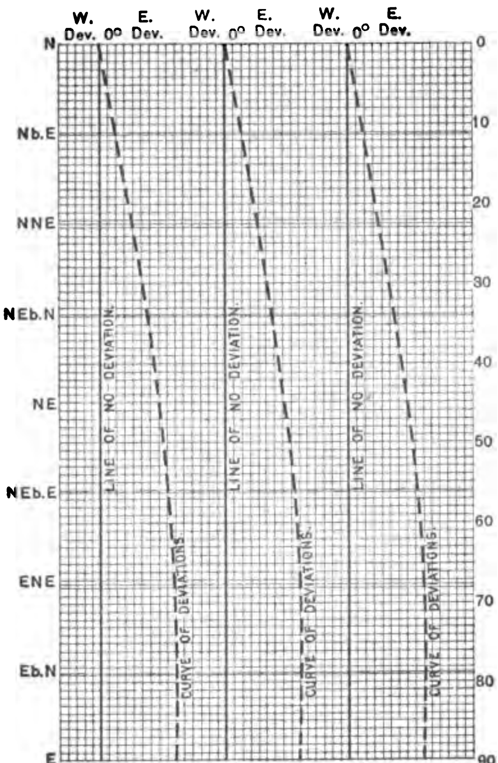
The three types of compass used in this experiment are represented in Plate VIII; and the length, number, weight, and arrangement upon the card, of their respective bundles of needles (which constitute the essential features of a compass) are sufficiently dissimilar to be differently affected by the soft iron tube placed as in Fig. 42, whi lifferences would appear in the deviations; yet, considering the instrumental and observational errors, and the effect of the distant pole of the tube on the compass, in the various headings of the vessel, the deviations of the three compasses, under the same conditions, as given in columns 4, 7, and 10, of Table XX, are nearly enough of the same value to warrant the conclusion that there is no practical difference in the deviations due to types of compass as extreme in variety as those used. For the same type of compass the deviations will be identical whether the needle be strong or weak in magnetism. This is experimentally proven (even by compasses of different type) by the deviations in columns 4 and 7, which are substantially identical, although one series is by the weak single needle of compass No. 6216, Fig. 1, Plate VIII, while the other is by the system of four powerful needles of No. 7860, Fig. 2, Plate VIII. This fact may also be easily shown from theoretical considerations. During the experiment the vessel was upright and swung through eastern quadrant, resting two minutes on each point.

Tube: 28 inches long, placed with axis horizontal, parallel to keel, and in plane of needle, nearest end 14 inches from compass pivot. It was not moved during the experiment; each compass was successively placed in the Y's and the observations made as indicated by the headings of the various columns of Table XX.

Experiment 22: *To determine what difference (if any) occurs in the when subjected to the influence of*

Table XXI.—*Observa*

Curves illustrating Experiment 22.
(Cols. 4, 7, and 10, Table XXI.)

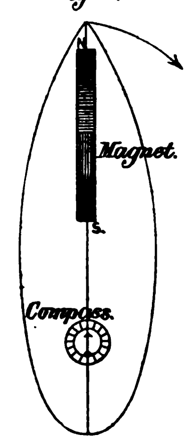


Compass No. 6216. Compass No 7860. Compass No. 3314.

Each small square is 1°.
Curve, natural size.

Heading of Scoresby by compass.	Bearing of True Meridian line on wall by compass No. 6216, *without* magnet on Scoresby.	Bearing of True Meridian line on wall by compass No. 6216, with magnet placed as in Fig. 43.
(1)	(2)	(3)
N.	N. 7° 20′ E.	N. 7° 20′ E.
N. by E.	N. 6 20 E.	N. 4 20 E.
N. NE.	N. 5 40 E.	N. 1 40 E.
NE. by N.	N. 4 55 E.	N. 0 50 W.
NE.	N. 4 05 E.	N. 2 50 W.
NE. by E.	N. 3 30 E.	N. 4 30 W.
E. NE.	N. 3 0 E.	N. 5 35 W.
E. by N.	N. 3 0 E.	N. 6 0 W.
E.	N. 3 0 E.	N. 6 05 W.

Fig. 43.



deviations of different types of compass, under the same circumstances, a permanent steel magnet alone.

tions: May 24, 1884.

Deviations of compass No. 6216, produced by magnet placed as in Fig. 43.	Bearing of True Meridian line on wall by compass No. 7860, *without* magnet on Scoresby.	Bearing of True Meridian line on wall by compass No. 7860, with magnet placed as in Fig. 43.	Deviations of compass No. 7860, produced by magnet placed as in Fig. 43.	Bearing of True Meridian line on wall by compass No. 3314, *without* magnet on Scoresby.	Bearing of True Meridian line on wall by compass No. 3314, with magnet placed as in Fig. 43.	Deviat'ns of compass No. 3314, produced by magnet placed as in Fig. 43.
(4)	(5)	(6)	(7)	(8)	(9)	(10)
0° 0′	N. 7° 10′ E.	N. 7° 25′ E.	0° 15′ W.	N. 7° 35′ E.	N. 8° 0′ E.	0° 25′ W.
2 0 E.	N. 6 30 E.	N. 4 35 E.	1 55 E.	N. 6 45 E.	N. 5 05 E.	1 40 E.
4 0 E.	N. 5 55 E.	N. 2 0 E.	3 55 E.	N. 5 55 E.	N. 2 25 E.	3 30 E.
5 45 E.	N. 5 0 E.	N. 0 35 W.	5 35 E.	N. 5 10 E.	N. 0 10 W.	5 20 E.
6 55 E.	N. 4 30 E.	N. 2 30 W.	7 0 E.	N. 4 30 E.	N. 2 25 W.	6 55 E.
8 0 E.	N. 4 0 E.	N. 4 10 W.	8 10 E.	N. 4 0 E.	N. 4 20 W.	8 20 E.
8 35 E.	N. 3 30 E.	N. 5 15 W.	8 45 E.	N. 3 30 E.	N. 5 25 W.	8 55 E.
9 0 E.	N. 3 10 E.	N. 5 55 W.	9 05 E.	N. 3 20 E.	N. 6 0 W.	9 20 E.
9 05 E.	N. 3 0 E.	N. 6 0 W.	9 0 E.	N. 3 0 E.	N. 6 0 W.	9 0 E.

EXPERIMENT 22: *Deviations of different types of compass under the same conditions of a permanent magnet.*

Vessel upright and swung through eastern quadrant, resting two minutes on each point. Magnet, a powerful steel bar 20 inches long and 1 inch square cross-section; placed with axis horizontal, in vertical section through keel, and in plane of needles, with its nearest (south) pole distant 39 inches from pivot of compass. It was not moved during the experiment; each compass was successively placed in the Y's, and the observations made as indicated by the headings of the various columns of Table XXI. The three compasses used were the same ones employed in Experiment 21, of which the description is given on Plate VIII. It will be observed that the deviations of these three widely different types of compass are almost identical; and this notwithstanding the power, size, and proximity of the disturbing magnet, which, of course, are of prime importance in considering the effect upon compass needles of different length and arrangement upon the card.

EFFECT UPON THE SAME TYPE OF COMPASS OF PLACING IT IN DIFFERENT PARTS OF THE SHIP.

To illustrate the effect upon the same type of compass of placing it in different parts of the ship, I select the case of the U. S. steamer Trenton (wood).

Upon being commissioned at New York in 1883, for flagship of the Asiatic squadron, the navigation officer of the yard, on September 19, reported, through the commandant, to the Bureau of Navigation, that with the vessel heading SSE. by standard compass, the two steering compasses differed 15°, and requested an explanation of it.

Plate IX represents the relative distances of the three compasses from each other and also the metal immediately surrounding them. To discover whether this metal was the cause of the difference, the Chief of Bureau, Captain Walker, directed on October 19, that observations for deviation be made at the points numbered (within parentheses) in the plate, at the constant height above the deck of the steering compasses when in their binnacles, the compasses, of course, being temporarily removed during the observations.

These observations, as received, are given in Table XXII; they are plotted on Plate IX, and the mean of those on each line, c-c, d-d, &c., is given within brackets.

It will be observed that the single readings on the line c-c do not differ much from the mean [S. 20° E.]; similarly those on the line f-f vary but slightly from the mean

[S. 25° 30′ E.]; and finally those on the line n-n. are not very wide of their mean value [S. 33° 23′ E.].

While this comparative uniformity on the same line exists, there is, however, a progressively increasing difference between the mean values of the three lines as we go from the starboard toward the port side.

This points to the chief cause of disturbance as resident in the sides of the ship (the port side being the stronger)—in the diagonal bracing and other iron similarly situated—and but slightly to the metal surrounding the compasses; for, if it were the latter, the individual observations on the same line would differ more widely than they do. The irregularity of the observations may readily be ascribed to the metal.

If any great effect were due to the barrel of the steering wheel and the steam steering wheel and their iron braces, the readings on each side would have been more divergent the nearer the compass was brought to the midship line; but such is not the case. Considering, then, the disturbing cause as existing in the sides of the vessel, as the distance from the acting pole varies, so will a varying divergence be noticed in the compass readings. This was the explanation offered by Bureau letter of November 9; and it was further stated: "In the direction in which the ship was heading, SSE., it is believed that the difference between the readings of the steering compasses was not far from its maximum value, and that on some courses it will be very small."

To test the correctness of this prediction, the commanding officer of the Trenton was directed to swing ship before leaving the United States, observing on every alternate

point the simultaneous readings of the standard and the two steering compasses.

This was done on December 1. Table XXIII is the result, and Plates X and XI are its graphical representation. Referring to the table and plates, it will be perceived that the *north* ends of the two steering compasses diverge on all headings but one of the ship, and that this divergence is a maximum at north and south and a minimum at east and west. This fulfills the prediction.

To explain the divergence, three hypotheses are admissible:

1*st.* That hard iron possessing magnetism as a permanent magnet does, (Plate XII) exists in the position of the steering wheel core; this would produce divergence during a complete swing, but it would be considerable in amount at east and west as compared with the standard compass, whereas the observations show it to be nothing at the latter point and only a mean of 2° at the former; therefore, if the core of the barrel of the wheel were the cause, this core could not be hard iron possessing permanent magnetism.

2*d.* That this core is *soft* iron which becomes magnetic by induction when in the meridian, and loses its magnetism when transverse to it. Let Plate XIII represent this. Then divergence will take place on all northerly courses, decreasing gradually to zero at east and west; so far this agrees with the observations, but on all southerly courses there will be convergence, owing to the reversal of the magnetism in the soft iron. Therefore, the iron cannot be soft, and the divergence cannot be wholly due to the

wheel barrel core. Similar reasoning will apply to all other iron in the immediate vicinity of the compasses.

3d. That the magnetism producing divergence resides in the sides of the ship—in the diagonal iron bracing, whose upper ends have south (blue) polarity, attractive of the north ends of the needle, and the port side stronger than the starboard (see Fig. 1, Plate X).

This will produce divergence on courses northerly as well as southerly, and the maximum will occur at north and south, while at east and west the three compasses will be alike, on account of the magnetic effect being in the prolongation of the needles, and this hypothesis substantially agrees with the observations in every particular.

Furthermore, on northerly as well as southerly courses, the two steering compasses will be equally steady; on easterly courses the port compass will be more steady than the starboard; on westerly courses the starboard will be more steady than the port compass, while the standard will be equally steady on all courses. This is evident from Fig. 1, Plate X.

TABLE XXII.

Showing the bearing of the ship's head by compass, at the points in the vicinity of the steering compasses numbered (in parentheses) on Plate IX.

[Observations made by the Navigation Officer of the New York Navy-Yard, November 1, 1883.]

(1)	(2)	(3)	(4)	(5)
Number of station.	Ship's head, by compass, carried to each station.	Corresponding heading by standard compass in its binnacle.	Ship's head, by compass, carried to the station.	Corresponding heading by standard compass in its binnacle.
	Muskets in rack around mizzen mast.		Muskets out of rack.	
1	S. 26° 0′ E.	S. 26° 30′ E.		
2	S. 24 30 E.	S. 26 30 E.		
3	S. 33 0 E.	S. 26 30 E.		
4	S. 18 0 E.	S. 26 30 E.		
5	S. 19 30 E.	S. 26 30 E.		
6	S. 30 0 E.	S. 26 30 E.		
7	S. 18 30 E.	S. 26 30 E.		
8	S. 31 30 E.	S. 26 30 E.		
9	S. 22 0 E.	S. 26 30 E.		
10	S. 30 30 E.	S. 26 30 E.		
11	S. 25 0 E.	S. 26 30 E.	S. 25° 30′ E.	S. 26 30 E.
12	S. 26 0 E.	S. 26 30 E.	S. 27 0 E.	S. 26 30 E.
13	S. 24 30 E.	S. 26 30 E.	S. 25 30 E.	S. 26 30 E.
14	S. 21 30 E.	S. 26 30 E.	S. 19 30 E.	S. 26 30 E.
15	S. 38 30 E.	S. 26 30 E.	S. 39 30 E.	S. 26 30 E.

PLATE IX.

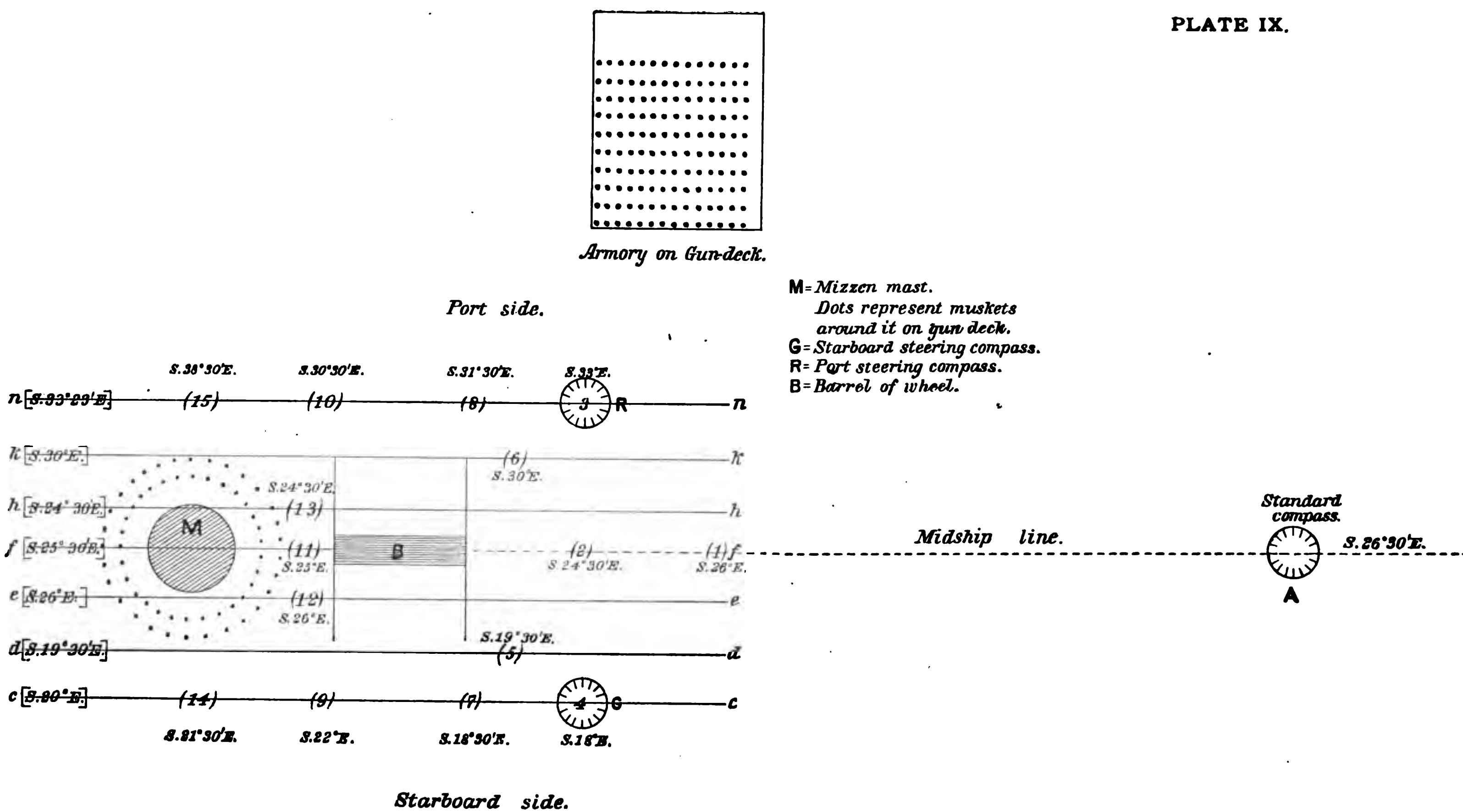

Armory on Gun-deck.
Port side.
M=Mizzen mast.
Dots represent muskets around it on gun deck.
G=Starboard steering compass.
R=Port steering compass.
B=Barrel of wheel.
S.28°30'E.
S.30°30'E.
S.31°30'E.
S.33°E.
(15)
(10)
(8)
R
S.30°E.
(6)
S.30°E.
S.24°30'E.
(13)
M
(11)
S.25°E.
B
(2)
S.24°30'E.
(1)
S.26°E.
(12)
S.26°E.
S.19°30'E.
(5)
(14)
(9)
(7)
G
S.21°30'E.
S.22°E.
S.18°30'E.
S.16°E.
Starboard side.
Midship line.
Standard compass.
S.26°30'E.
A

TABLE XXIII.

Simultaneous observations on every alternate point of the standard and steering compasses of the U. S. S. Trenton.

Date of observation...	December 1, 1883.	December 1, 1883.	Difference between the starboard and port steering compasses on each course.	
Place of observation..	Off Sandy Hook.	Off Sandy Hook.		
Latitude	40° 21′ N.	40° 21′ N.		
Longitude............	73° 52′ W.	73° 52′ W.		
Name of observer....	Lieut. Asa Walker.	Lieut. Asa Walker.		
Compass	Starboard steering.	Port steering.		
(1)	(2)	(3)	(4)	
Ship's head by standard compass.	Ship's head by Stbd. (No. 71) steering.	Ship's head by Port (No. 345) steering.	Points.	Degrees.
N.	N. ½ W.	N. ½ E.	1 pt.	11° 15′
N. by E.				
N. NE.	N. by E. ⅝ E.	N. NE. ¾ E.	1⅛ "	12 39
NE. by N.				
NE.	NE. ⅜ N.	NE. ⅜ E.	¾ "	8 26
NE. by E.				
E. NE.	E. NE.	E. NE. ½ E.	½ "	5 37
E. by N.				
E.	E. ¼ S.	E. ⅜ S.	⅛ "	1 24
E. by S.				
E. SE.	SE. by E. ⅜ E.	E. SE. ¼ E.	¾ "	8 26
SE. by E.				
SE.	SE. ⅜ S.	SE. ¾ E.	1¼ "	14 03
SE. by S.				
S. SE.	S. by E. ⅝ E.	S. SE. ¾ E.	1⅜ "	15 28
S. by E.				
S.	S. ¾ W.	S. ⅞ E.	1⅝ "	18 16
S. by W.				
S. SW.	S. SW. ½ W.	S. by W.	1½ "	16 52
SW. by S.				
SW.	SW. ½ W.	SW. ¾ S.	1¼ "	14 03
SW. by W.				
W. SW.	W. SW.	SW. by W. ½ W.	"	5 37
W. by S.				
W.	W.	W.	0	0
W. by N.				
W. NW.	W. NW. ½ W.	W. NW.	½ "	5 37
NW. by W.				
NW.	NW. ¾ W.	NW. ¼ N.	1 "	11 15
NW. by N.				
N. NW.	N. NW. ½ W.	N. by W. ⅜ W.	1⅛ "	12 39
N. by W.				

[*Note to accompany Experiment* 23: ***Production of the Semicircular Deviation and its Compensation.***]

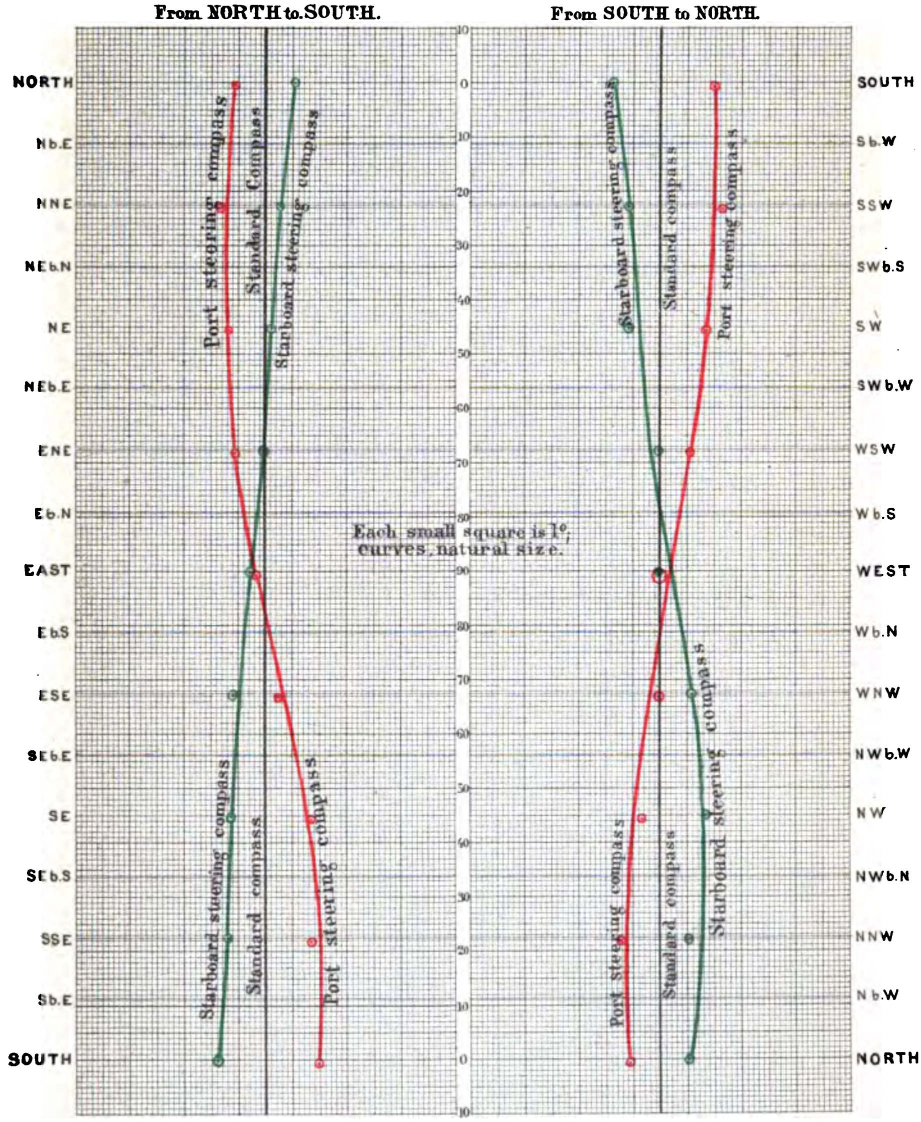
The compass used in this experiment was the new liquid four-needle type, No. 6211, which was in every particular like No. 7860 described in Fig. 2, Plate VIII.

All iron, magnets, and other disturbing materials were first removed from proximity to the Scoresby, and the vessel swung until the pointer on the bow successively indicated equal (true) arcs of the brass circle on the floor, column (1), Table XXIV. The corresponding heading of the vessel by compass was observed and recorded, column (2), Table XXIV. A solid steel cylindrical magnet, 9½ inches long and 1¼ inches in diameter, was then placed horizontally in the plane of the compass needles, in a line bearing 45° on starboard bow, south pole directed toward compass, and 20 inches from its pivot (see Plate XIV, "disturbing magnet".) The vessel was again swung through 360°, resting two minutes on each exact division of 20° of the brass circle on the floor, and the heading of the vessel by compass was observed, column (3), Table XXIV. A comparison of columns (2) and (3) gave the deviations, column (4), caused by the "disturbing magnet." Sixteen thin bar magnets, eight 11¼ inches long, and eight 8½ inches long, were now placed below the compass, and 29 inches from the plane of the needles, their length being in a vertical plane making an angle of 45° with the vertical plane through the keel, north poles all turned toward the "disturbing magnet" (see group of "compensating magnets" in Plate XIV). The vessel was then swung through 360°, resting two minutes on each

Plate XI.

Curves illustrating Table XXIII, simultaneous observations on every alternate point of the standard and steering compasses of the U.S.S. Trenton.

RECTANGULAR COMPASS DIAGRAM.



S.W.B. Diehl } del.

Plate XII.

1st. hypothesis; hard iron possessing permanent magnetism in the barrel of the steering wheel.

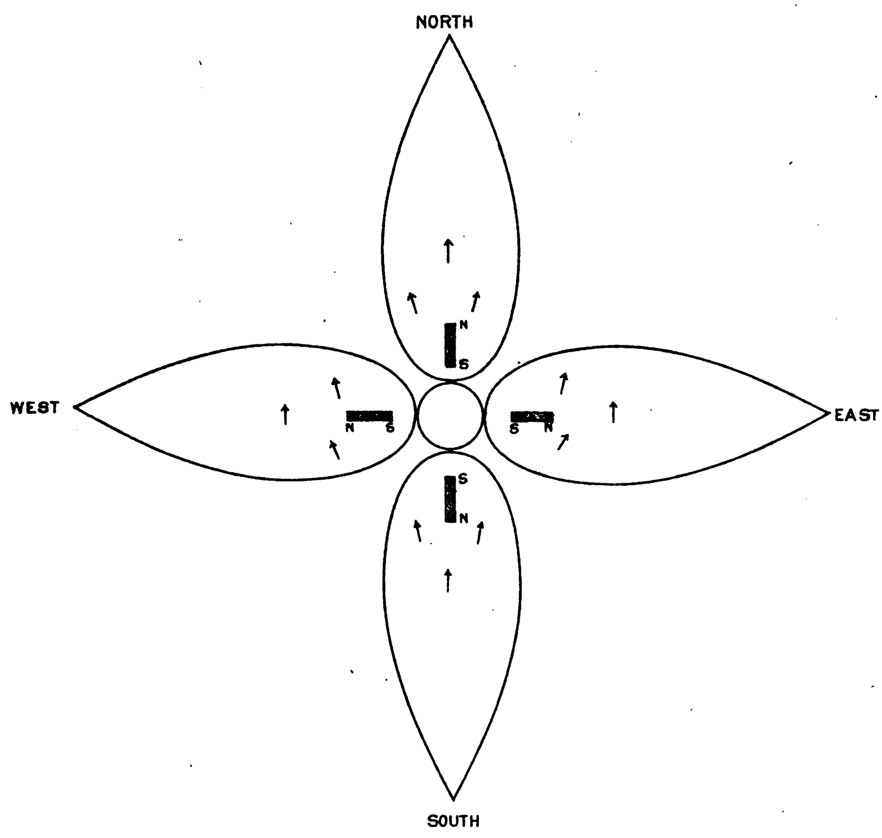
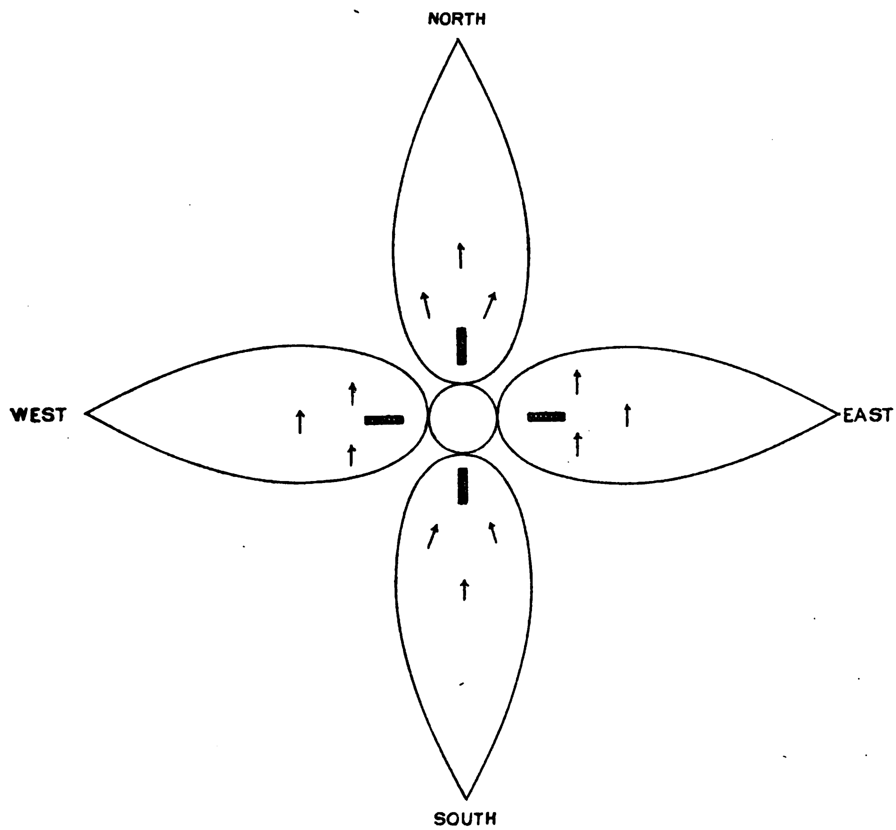


Plate XIII.

2d. hypothesis; soft iron affected by induced magnetism only, in barrel of steering wheel.



division of 20° of the brass circle, and the heading of the Scoresby noted and recorded, column (5), Table XXIV. The residual deviations are given in column 6 of that table. The system of "compensating magnets" was then raised 1½ inches, without turning them in azimuth, the vessel swung as before, column 7, and a final table of residuals obtained, column (8), which being very small in amount, the maximum attaining only 1°, the compass was deemed compensated. The curves illustrative of the different series of deviations, without compensation at all, partially compensated, and finally compensated, are all given in Plate XV.

Before placing the "compensating magnets" on the Scoresby, in the northern semicircle, that is, from east by the way of north to west, the compass was very steady and came quickly to rest, because the south pole of the "disturbing magnet" was attracting the north poles of the needles; also, for equal true arcs of the horizon, column 1, the corresponding compass arcs are very much less, besides being variable, column 3, diff.: in the southern semicircle, on the other hand, the compass was unsteady and required some time to come to rest, because the south pole of the "disturbing magnet" repelled the south ends of the compass needles; also for equal *true* arcs of the horizon, column 1, the corresponding compass arcs are very much larger, and variable, column 3 diff.

This inequality between the true and compass arcs before compensation, disappears after compensation, column 7 diff.

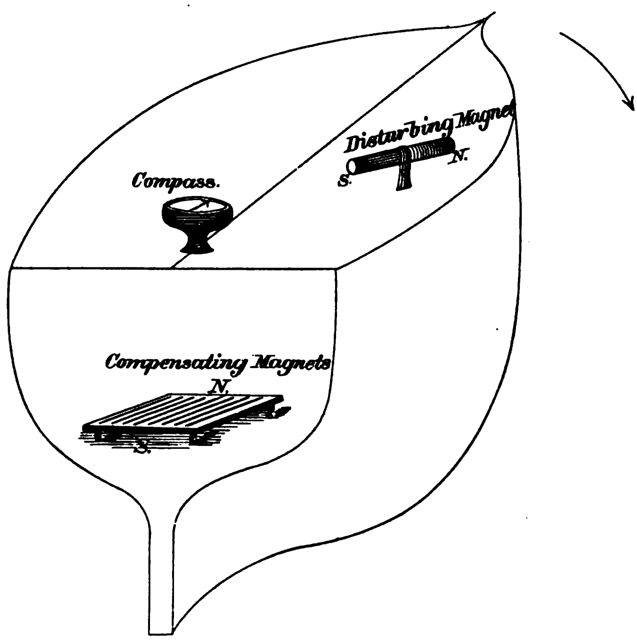
EXPERIMENT 23: *Compensation*

TABLE XXIV.—*Observations with*

(1)	(2)		(3)		(4)
Heading of Scoresby by brass circle on floor, *without* disturbing or compensating magnets on the vessel.	Corresponding reading of compass No. 6211; *no* magnets on Scoresby.		Corresponding reading of compass No. 6211, with a disturbing magnet placed in a "starboard angle" of 45°, south pole nearest compass, magnet horizontal and axis in plane of compass needles.		Deviations produced by disturbing magnet = Difference of columns (2) and (3).
Headings, True.	Headings, magnetic.	Differences.	Headings by compass.	Differences.	Deviations.
N. 0° W.	N. 5° E.		N. 11° W.		16° E.
N. 20 W.	N. 15 W.	20°	N. 25 W.	14°	10 E.
N. 40 W.	N. 36 W.	21	N. 39 W.	14	3 E.
N. 60 W.	N. 57 W.	21	N. 53 W.	14	4 W.
N. 80 W.	N. 77 W.	20	N. 67 W.	14	10 W.
N. 100 W.	S. 83 W.	20	N. 81 W.	14	16 W.
N. 120 W.	S. 63 W.	20	S. 84 W.	15	21 W.
N. 140 W.	S. 44 W.	19	S. 68 W.	16	24 W.
N. 160 W.	S. 24 W.	20	S. 51 W.	17	27 W.
N. 180 W.	S. 5 W.	19	S. 31 W.	20	26 W.
N. 200 W.	S. 15 E.	20	S. 6 W.	25	21 W.
N. 220 W.	S. 34 E.	19	S. 25 E.	31	9 W.
N. 240 W.	S. 54 E.	20	S. 61 E.	36	7 E.
N. 260 W.	S. 74 E.	20	N. 86 E.	33	20 E.
N. 280 W.	N. 86 E.	20	N. 59 E.	27	27 E.
N. 300 W.	N. 66 E.	20	N. 38 E.	21	28 E.
N. 320 W.	N. 46 E.	20	N. 20 E.	18	26 E.
N. 340 W.	N. 26 E.	20	N. 4 E.	16	22 E.
N. 0 W.	N. 5 E.	21	N. 11 W.	15	16 E.

PLATE XIV.

Production of the Semicircular Deviation, and its compensation.



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oresby, Sc

Reading ... ell, wi... ing ma... inches ... low th... pass to... of dis... N. end
Heading ... p
N.
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of the Semicircular Deviation.

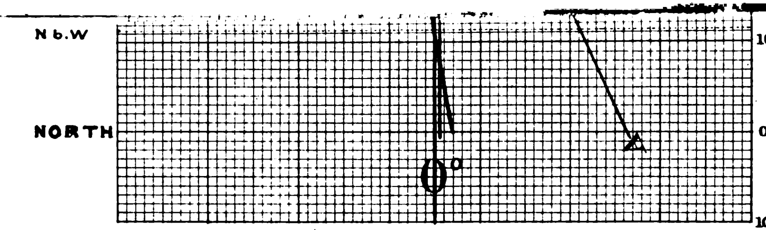
Scoresby, September 18, 1884.

(5)		(6)	(7)		(8)
Reading of compass No. 6211, with 16 compensating magnets placed 29 inches immediately below the plane of compass to overcome effect of disturbing magnet. N. ends 45° on bow.		Residual deviations after compensation in column (5).	Reading of compass No. 6211, after raising the system of compensating magnets of column (5) 1¼ inches, vertically, *without* changing the direction of their starboard angle.		Final Residual Deviations after complete compensation = Difference of columns (2) and (7).
Headings by compass.	Differences.	Deviations.	Headings by compass.	Differences.	Deviations.
N. 4° E.	18°	1° E.	N. 4° 30′ E.	20° 30′	0° 30′ E.
N. 14 W.	19	1 W.	N. 16 0 W.	21 0	1 0 E.
N. 33 W.	19	3 W.	N. 37 0 W.	19 30	1 0 E.
N. 52 W.	20	5 W.	N. 57 30 W.	20 30	0 30 E.
N. 72 W.	19	5 W.	N. 78 0 W.	19 30	1 0 E.
S. 89 W.	21	6 W.	S. 82 30 W.	20 0	0 30 E.
S. 68 W.	20	5 W.	S. 62 30 W.	21 0	0 30 E.
S. 48 W.	21	4 W.	S. 43 30 W.	19 0	0 30 E.
S. 27 W.	22	3 W.	S. 24 0 W.	19 0	0 0
S. 5 W.	21	0	S. 5 0 W.	19 30	0 0
S. 16 E.	22	1 E.	S. 14 30 E.	19 0	0 30 W.
S. 38 E.	21	4 E.	S. 33 30 E.	19 30	0 30 W.
S. 59 E.	20	5 E.	S. 53 0 E.	20 0	1 0 W.
S. 79 E.	20	5 E.	S. 73 0 E.	20 0	1 0 W.
N. 81 E.	20	5 E.	N. 87 0 E.	20 30	1 0 W.
N. 61 E.	19	5 E.	N. 66 30 E.	20 30	0 30 W.
N. 42 E.	19	4 E.	N. 46 0 E.	20 30	0 0
N. 23 E.	19	3 E.	N. 25 30 E.	21 0	0 30 W.
N. 4 E.		1 E.	N. 4 30 E.		0 30 W.

[*Note to accompany Experiment* 24: *Production of the Quadrant*
Deviation and its Compensation.]

The mode of procedure in this experiment was entirel
analogous to that in Experiment 23.

Plate XVI represents the disposition of both the so
iron tubes—the disturbing and the compensating; Tabl
XXV gives the details of the observations; and Plate XVI
their graphical representation. The maximum of 2° in th
residual deviations after compensation is no doubt largel
due to the inequality in the tubes and the difficulty of plac
ing them exactly at right angles to each other, in connec-
tion with such errors as are unavoidable.

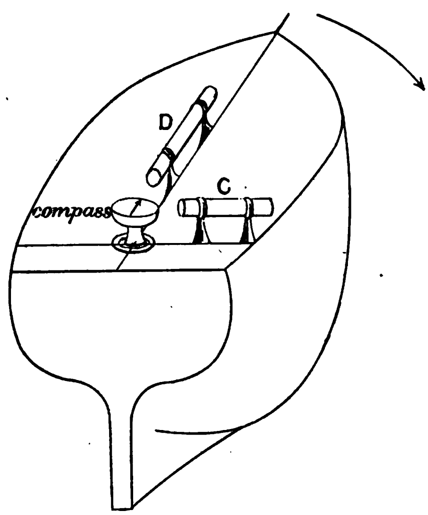


Curves of Deviations of Compass No. 6211, on the "Scoresby";

A A: Deviations produced by disturbing magnet.
B B: Residual deviations after partial adjustment of compensating magnets.
C C: Residual deviations after final adjustment of compensating magnets.
D D: Line of no Deviations.

PLATE XVI.

Production of the quadrantal-deviation, and its compensation.



**D, disturbing soft-iron tube placed as described in column (3), Table XXV.
C, compensating soft-iron tube, similar to D, placed at right angles to it, as described in column (5), Table XXV.**

Experiment 24: Compensation of the Quadrantal Deviation.

EXPERIMENT 24: *Compensation*

TABLE XXV.—*Observations with the*

(1)	(2)		(3)	
Heading of Scoresby by brass circle on floor; no soft iron whatever acting on compass.	Corresponding reading of Compass No. 6211; no soft iron whatever on the Scoresby.		Corresponding reading of Compass No. 6211, with a soft iron tube placed entirely forward of compass, axis horizontal, in vertical plane through keel, and in plane of needles; nearest end ten inches from pivot.	
Headings, true.	Headings, magnetic.	Differences.	Headings, by compass.	Differences.
N. 0° W.	N. 5° 00′ E.	°	N. 4° 30′ E.	°
		20.5		17.5
N. 20 W.	N. 15 30 W.		N. 13 00 W.	
		20.5		17.5
N. 40 W.	N. 36 00 W.		N. 30 30 W.	
		20.5		20.0
N. 60 W.	N. 56 30 W.		N. 50 30 W.	
		20.5		23.0
N. 80 W.	N. 77 00 W.		N. 73 30 W.	
		20.0		25.5
N. 100 W.	S. 83 00 W.		S. 81 00 W.	
		20.0		24.4
N. 120 W.	S. 63 00 W.		S. 57 00 W.	
		19.5		20.5
N. 140 W.	S. 43 30 W.		S. 36 30 W.	
		19.5		17.0
N. 160 W.	S. 24 00 W.		S. 19 30 W.	
		19.0		15.5
N. 180 W.	S. 5 00 W.		S. 4 00 W.	
		20.0		15.5
N. 200 W.	S. 15 00 E.		S. 11 30 E.	
		19.5		16.5
N. 220 W.	S. 34 30 E.		S. 28 00 E.	
		19.5		18.0
N. 240 W.	S. 54 00 E.		S. 46 00 E.	
		20.0		21.0
N. 260 W.	S. 74 00 E.		S. 67 00 E.	
		20.0		25.0
N. 280 W.	N. 86 00 E.		N. 88 00 E.	
		20.0		25.0
N. 300 W.	N. 66 00 E.		N. 63 00 E.	
		20.0		22.5
N. 320 W.	N. 46 00 E.		N. 40 30 E.	
		20.5		18.5
N. 340 W.	N. 25 30 E.		N. 22 00 E.	
		20.5		17.5
N. 360 W.	N. 5 00 E.		N. 4 30 E.	

of the Quadrantal Deviation.

Scoresby: September 22, 1854.

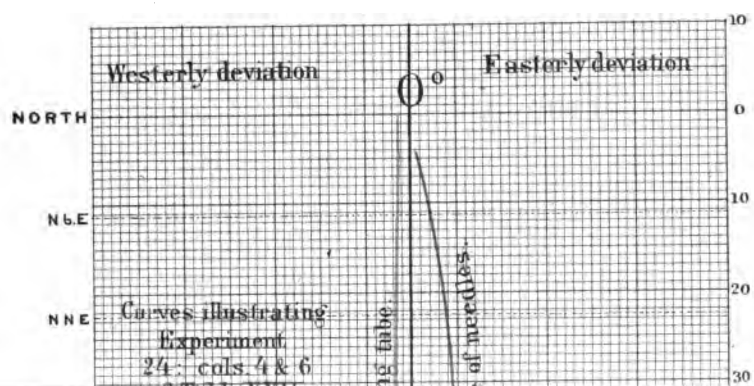
(4)	(5)		(6)
Deviations produced by soft iron tube = difference of columns (2) and (3).	Reading of Compass No. 6211, after the deviations of column (4) were partly compensated by placing a soft iron tube similar to the one used for causing the deviations in the transverse plane through pivot of compass, on the starboard side.		Residual deviations after compensation of the quadrantal deviations.
Deviations.	Headings, by compass.	Differences.	Deviations.
0° 30′ E.	N. 5° 30′ E.	°	0° 30′ W.
		20.5	
2 30 W.	N. 15 00 W.		0 30 W.
		20.5	
5 30 W.	N. 35 30 W.		0 30 W.
		20.5	
6 00 W.	N. 56 00 W.		0 30 W.
		21.0	
3 30 W.	N. 77 00 W.		0 00 —
		21.0	
2 00 E.	S. 82 00 W.		1 00 E.
		20.5	
6 00 E.	S. 61 30 W.		1 30 E.
		19.5	
7 00 E.	S. 42 00 W.		1 30 E.
		18.5	
4 30 E.	S. 23 30 W.		0 30 E.
		19.0	
1 00 E.	S. 4 30 W.		0 30 E.
		19.0	
3 30 W.	S. 14 30 E.		0 30 W.
		19.0	
5 30 W.	S. 33 30 E.		1 00 W.
		19.0	
8 00 W.	S. 52 30 E.		1 30 W.
		19.5	
7 00 W.	S. 72 00 E.		2 00 W.
		20.0	
2 00 W.	N. 88 00 E.		2 00 W.
		20.0	
3 00 E.	N. 68 00 E.		2 00 W.
		21.0	
5 30 E.	N. 47 00 E.		1 00 W.
		19.5	
8 30 E.	N. 27 30 E.		2 00 W.
		20.5	
0 30 E.	N. 7 00 E.		2 00 W.

EXPERIMENT 25: ***Production of the***

TABLE XXVII.—*Observations:*

Heading of the Scoresby by brass circle on floor of room.	Corresponding heading of Scoresby by compass No. 6211; vessel upright, and no iron or magnets on her or in the immediate proximity.	Corresponding heading of Scoresby by compass No. 6211; vessel *upright*, and disturbing magnet placed entirely above compass, axis of magnet coinciding with axis of compass; nearest end of magnet 11 inches from plane of needles.	Deviations produced by disturbing magnet, placed as in column 3, vessel *upright*; difference of columns 2 and 3.	Heading of Scoresby by compass No. 6211; vessel *heeled* 20° *to starboard*, corresponding to headings of vessel by brass circle in column 1; no magnet or iron on vessel nor in immediate proximity.
(1)	(2)	(3)	(4)	(5)
N. 0°	N. 5° 15′ E.	N. 5° 30′ E.	0° 15′ W.	N. 8° 45′ E.
N. 20 W.				N. 11 30 W.
N. 40 W.	N. 35 45 W.	N. 35 30 W.	0 15 W.	N. 32 0 W.
N. 60 W.				N. 52 45 W.
N. 80 W.	N. 77 0 W.	N. 76 15 W.	0 45 W.	N. 73 45 W.
N. 100 W.				S. 85 45 W.
N. 120 W.	S. 63 15 W.	S. 63 45 W.	0 30 W.	S. 65 15 W.
N. 140 W.				S. 45 15 W.
N. 160 W.	S. 24 15 W.	S. 24 30 W.	0 15 W.	S. 25 30 W.
N. 180 W.				S. 5 45 W.
N. 200 W.	S. 14 30 E.	S. 14 45 E.	0 15 E.	S. 13 30 E.
N. 220 W.				S. 33 0 E.
N. 240 W.	S. 54 0 E.	S. 54 0 E.	0 0	S. 52 0 E.
N. 260 W.				S. 71 30 E.
N. 280 W.	N. 86 30 E.	N. 86 15 E.	0 15 E.	N. 89 0 E.
N. 300 W.				N. 69 0 E.
N. 320 W.	N. 46 0 E.	N. 46 30 E.	0 30 W.	N. 49 0 E.
N. 340 W.				N. 29 0 E.
N. 360 W.	N. 5 30 E.	N. 5 45 E.	0 15 W.	N. 8 45 E.

Plate XVII.


Westerly deviation
Easterly deviation
0°
NORTH
N b. E
NNE
10
0
10
20
30
Curves illustrating
Experiment
24 : cols. 4 & 6
ng tube.
of needles.

Heeling Deviation and its Compensation.

October 20, 1884.

Heading of Scoresby by compass No. 6211; vessel heeled 20° to starboard, corresponding to headings of vessel by brass circle in column 1; disturbing magnet placed above compass, axis of magnet in axis of compass; nearest end of magnet 11 inches from plane of needles. See Plate XIX.	Heeling deviations produced by disturbing magnet placed as stated in column (6); vessel heeled 20° to starboard. Difference of columns (5) and (6).	Headings of Scoresby by compass No. 6211, *after* placing the compensating magnet below the compass, its axis in axis of compass; nearest end 12 inches from plane of needles. See Plate XIX.	Residual heeling deviations after compensation; vessel heeled 20° to starboard. Difference of columns (5) and (8).	Heading of Scoresby by compass No. 6211 corresponding to column 1; vessel upright, disturbing magnet removed, and compensating magnet in place as in Plate XIX.	Deviations produced by compensating magnet, vessel upright. Difference of columns (2) and (10).
(6)	(7)	(8)	(9)	(10)	(11)
N. 29° 0′ E.	20° 15′ W.	N. 9° 0′ E.	0° 15′ W.	N. 4° 30′ E.	0° 45′ E.
N. 11 30 E.	23 0 W.	N. 10 45 W.	0 45 W.		
N. 8 30 W.	23 30 W.	N. 30 30 W.	1 30 W.	N. 35 15 W.	0 30 W.
N. 31 45 W.	21 0 W.	N. 51 0 W.	1 45 W.		
N. 62 30 W.	11 15 W.	N. 71 30 W.	2 15 W.	N. 75 30 W.	1 30 W.
S. 84 0 W.	1 45 E.	S. 87 45 W.	2 0 W.		
S. 52 0 W.	13 15 E.	S. 67 0 W.	1 45 W.	S. 65 0 W.	1 45 W.
S. 25 15 W.	20 0 E.	S. 46 30 W.	1 15 W.		
S. 2 45 W.	22 45 E.	S. 26 15 W.	0 45 W.	S. 25 0 W.	0 45 W.
S. 16 15 E.	22 0 E.	S. 6 0 W.	0 15 W.		
S. 33 0 E.	19 30 E.	S. 14 30 E.	1 0 E.	S. 14 30 E.	0 0
S. 48 15 E.	15 15 E.	S. 34 30 E.	1 30 E.		
S. 63 0 E.	11 0 E.	S. 54 0 E.	2 0 E.	S. 54 45 E.	0 45 E.
S. 77 15 E.	5 45 E.	S. 74 0 E.	2 30 E.		
N. 88 30 E.	0 30 E.	N. 87 0 E.	2 0 E.	N. 85 15 E.	1 15 E.
N. 75 45 E.	6 45 W.	N. 67 0 E.	2 0 E.		
N. 60 0 E.	11 0 W.	N. 47 30 E.	1 30 E.	N. 45 30 E.	0 30 E.
N. 45 0 E.	16 0 W.	N. 28 0 E.	1 0 E.		
N. 29 0 E.	20 15 W.	N. 8 45 E.	0 0	N. 4 45 E.	0 45 E.

Experiment 25: Production of the Heeling Deviation and its Compensation.

Compass No. 6211, which is in every respect like No. 7860, previously described, having been placed on the Scoresby, the vessel, while upright, was swung until the pointer on the bow successively pointed to every 40°-division of the brass circle on the floor, and the corresponding heading by the compass and circle were noted and recorded, columns (1) and (2), Table XXVII. A solid steel cylindrical magnet, the disturbing magnet D of Plate XIX, 9¼ inches long and 1¼ inches in diameter, was then placed above the compass, its axis as nearly as possible in the prolongation of the axis of the compass, and the north (nearest) end 11 inches from the plane of the needles. The vessel, while upright, was again swung, column (3), to ascertain any disturbing effect from want of verticality of the magnet D; the results are given in column 4. Without moving in the least the arm that held the magnet D, the latter was withdrawn, and together with all other magnets and iron, was removed to some distance from the Scoresby. The vessel was now heeled 20° to starboard and swung, column (5). The magnet D was then carefully returned to its holder, Plate XIX, and the vessel swung, column (6). The heeling deviations to the high side thus produced by D are recorded in column (7),

and are represented by the curves B-B, Plate XX. A compensating magnet, C, Plate XIX, in every respect similar to D, was then placed symmetrically to D, below the compass, its north (nearest) end 12 inches from the plane of the needles, and the vessel swung, column (8). A comparison of columns (5) and (8) gives the residual deviations, column (9), after compensation; they are represented in the curve C-C, Plate XX. Finally, to ascertain the effect of the compensating magnet, due to want of verticality, the vessel was brought to upright, the magnet D removed, and the vessel swung, column (10), a comparison of which with column (2) shows the results in column (11).

INDUCED MAGNETISM.

Induced magnetism should be regarded as the most important, *because the most variable*, factor in the deviations of the compass.

Some writers call it retentive magnetism. The name is of less importance than a clear idea of the phenomenon for which it stands, and my endeavor, in the few remarks I shall make upon it, will be to define it and point out some of its effects.

Strictly speaking, I suppose that all magnetism may be said to be the result of induction.

The earth induces magnetism in the hull of a vessel while building; hammering only aids its reception and gives it a permanent home. So with a piece of steel stroked with a bar-magnet; it also becomes a permanent magnet through induction. Yet it is of neither of these that I wish to speak, but of that mild influence of the earth which renders magnetic every piece of iron, the poles of which then move and shift and occupy successively the various parts of the iron that come into the magnetic meridian as we turn the iron round and about. Let us conceive a metallically pure cylinder of wrought, or cast iron, that has not been hammered, and let us further conceive it entirely free from magnetism. Hold it vertically, and instantly the upper end becomes a south, and the

PLATE XIX.

Experiment 25: Production of the heeling deviation, and its compensation.

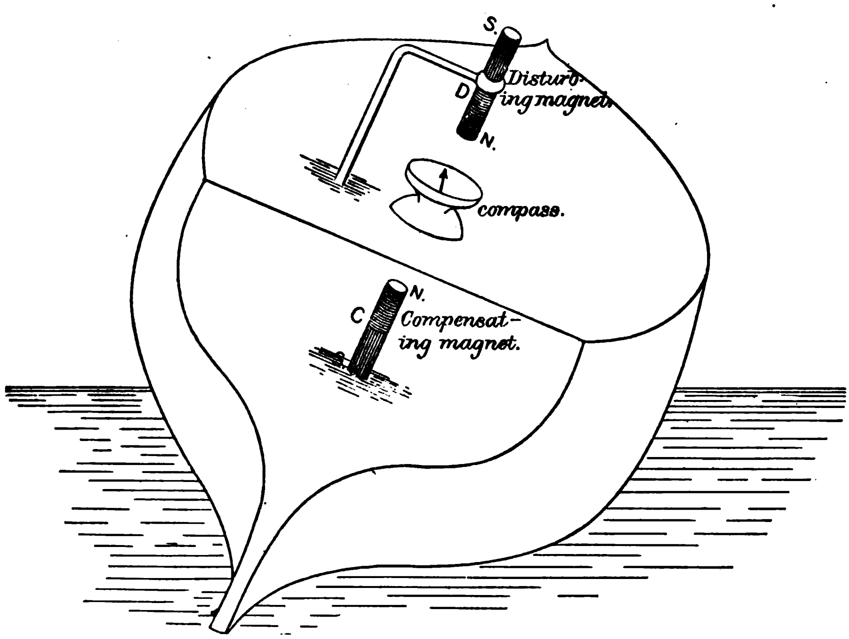
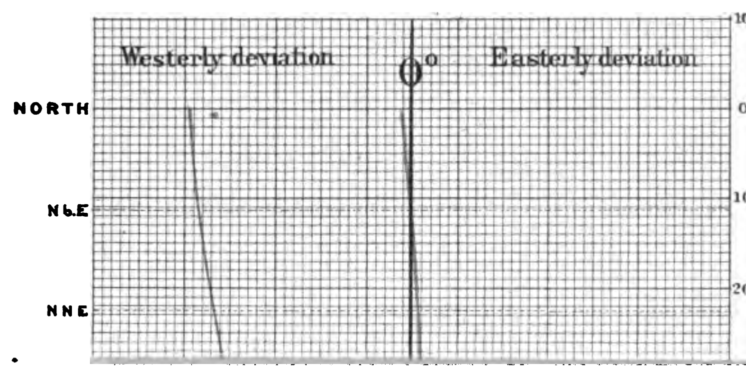


Plate XX.

Experiment 25: Production of the Heeling Deviation, and its compensation.
Curves illustrative of Cols. 7 and 9, Table XXVII.



lower, a north, pole. Reverse it as quickly as we may, and the magnetism also reverses, so that the upper and lower ends are still as they were before—a south and a north pole respectively. Hold it horizontally in the meridian, and the end toward the north becomes a north pole, while that toward the south becomes a south pole. Revolve it slowly, or rapidly, in azimuth, and the foci of magnetic polarity also move with the fidelity of a shadow, until, when the cylinder points east and west, all the side facing the north is pervaded by north magnetism, and all facing the south, by south magnetism.

Again: let us conceive the hull of a ship to be like our cylinder, of metallically pure wrought iron, and as susceptible of magnetic induction in its ever-changing courses as the cylinder is when turned round. Then as the ship steers north (in this latitude) the bow will become the center of north polarity, and the stern that of south polarity. As she gradually changes course to the eastward, so will the north focus shift to the port bow, the south focus to the starboard quarter, and the neutral line dividing them, which, while the ship headed north was athwartship, will now become a diagonal from starboard bow to port quarter.

When the ship heads east, all the starboard side is pervaded with south polarity, the port with north, and the neutral line takes a general fore-and-aft direction. Continuing to change course to the southward, the poles and neutral line continue their motion in the opposite direction, until at south the conditions at north are repeated, but this time it is the stern that is a north pole, while the

bow is a south pole. At west the conditions at east prevail, only that it is now the starboard side that has north polarity, and the port side south polarity.

And this transitory induction in both the cylinder and the ideal vessel is the induced magnetism which I deem of prime importance.

Now, to consider it in connection with an actual ship. The hull of no vessel is metallically pure, nor has it acquired shape and stability without much hammering; moreover, it cannot be made an abstraction from a magnetic state. Therefore, it is not as susceptible of the mild magnetic induction of the earth as the cylinder and ideal hull, although the straining while on a passage, and the buffeting of the waves do assist the inducing tendency; besides, once that the induced magnetism becomes lodged, it does not move and shift with the freedom and facility that it did in the cylinder; and finally, as it already finds a tenacious occupant of the vessel in its permanent magnetism, it must adapt itself to the greater power, and thus it is the resultant of both we always find, and not the individuality of either.

Time is a chief element in the acquisition and efficacy of this induced magnetism; for the longer a ship steers on a given course, or lies in the same general direction, the greater will be the magnetic charge, and the more slowly will it move and shift with the changing courses of the vessel.

It is to obtain some precise data relative to this induced magnetism, and to guard well against any unfortunate accidents that may result from its presence, that the follow-

ing two clauses are inserted in the directions printed on the Compass Reports to be made out by ships, which have recently been devised and issued by the Bureau of Navigation.

IV. When circumstances permit, *immediately* upon leaving any port in which the vessel has been for two weeks or more in the same general direction, whether moored head and stern, or fast to a wharf, or, while on a passage, steering the same general course for a week or so, the Compass Errors, with ship upright, shall be determined for the eight equidistant points N., NE., E., &c., and the data entered in *red* ink in division D.

VI. When approaching a coast the Compass Errors for some of the principal courses likely to be steered should be determined. Results to be entered on division D.

Instead of attributing the loss of vessels when approaching a coast to the magnetic effects of fogs and land, and other improbable influences upon the compass, it were much more reasonable to ascribe it to the changed conditions of her magnetism by *induction* during the passage, and which has not been discovered, or kept account of by frequent azimuths previous to closing in with the land. Suddenly, a course the captain thought perfectly safe, carries the ship upon a shoal or rock, and the fault is laid upon the compasses, whereas they but obeyed the magnetic influences that became altered during a long passage, from what these influences were when the ship was last swung; or the accident is absurdly laid upon magnetic fogs, proximity to magnetic land, &c.

In support of the opinion that induced magnetism plays an important part in altering the so-called permanent mag-

netism of a ship, I refer to the following Table XXVI and Plate XVIII.

In the table we have two series of deviations of the U. S. Iron-clad Passaic.

The first series, November 15, was observed immediately after coming out of the Norfolk dry-dock, in which she had lain for several weeks with her head nearly west—really N. 73° W. It will be seen that the starboard angle was then 328° 20′; the coefficient B, + 11° 06′; C, — 7° 25′; and the deviation at north, 8° 27′ W.

In the second series, observed some time subsequently (and she had done some cruising in the interval), we find these quantities as follows: starboard angle = 346° 13′; B = + 13° 07′; C = — 3° 24′; and deviation at north, 4° 15′ W. Thus, the starboard angle increased 18°, and B 2°, while C decreased 4° and the deviation at north, 4°—all of which point to a movement or shifting of the resultant magnetism of the ship from the sides *toward* the bow; and the phenomenon of induced magnetism, considered in connection with the direction of the vessel just previous to the first series of observations, and her subsequent cruising, will reasonably and satisfactorily explain this change.

Again. Consider the magnetic surveys of the Albatross on Plate XVIII.

This vessel was built with her head nearly *north*, and this characteristic is shown in Fig. 1, notwithstanding that the survey was made with her head S. 33° W.

Fig. 2, Plate XVIII, represents a subsequent survey made with the head N. 73° W., and it shows a decided

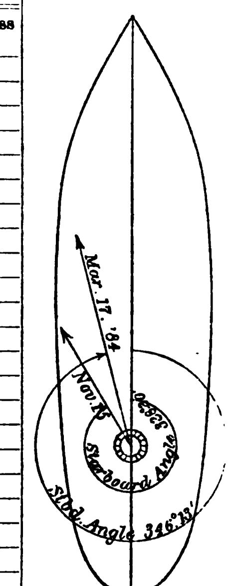
change in the magnetism of the hull—the characteristic of a ship built head west being evident.

This change in the original magnetism of the hull can also be reasonably accounted for by the earth's induction while the ship lay in the Norfolk dry-dock.

TABLE XXVI.

Deviations of the standard compass of the U. S. Iron-clad Passaic.

Date of observation...	November 15, 16, 1882.	March 17, 1884.
Place of observation	Piney Point, Potomac River.	Off Annapolis, Md.
Latitude..............	38° 08′ N.	38° 59′ N.
Longitude	76° 32′ W.	76° 29′ W.
Name of observer	Lieut. N. R. Usher.	Naval Cadets, class of 1884.
Office index letter.....		
(1)	(2)	(3)
Ship's head by standard compass.	Deviation by compass No. 237.	Deviation by compass No. 237.
N.	8° 27′ W.	4° 15′ W.
N. by E.	4 04 W.	0 15 E.
N. NE.	0 23 W.	4 30 E.
NE. by N.	3 48 E.	7 15 E.
NE.	6 18 E.	10 0 E.
NE. by E.	7 58 E.	12 0 E.
E. NE.	10 20 E.	12 0 E.
E. by N.	11 33 E.	12 25 E.
E.	11 46 E.	12 45 E.
E. by S.	10 20 E.	12 0 E.
E. SE.	9 10 E.	10 50 E.
SE. by E.	9 27 E.	9 15 E.
SE.	8 39 E.	8 35 E.
SE. by S.	7 27 E.	6 25 E.
S. SE.	8 24 E.	5 30 E.
S. by E.	7 36 E.	4 25 E.
S.	6 56 E.	3 0 E.
S. by W.	6 0 E.	0 45 E.
S. SW.	5 37 E.	0 15 W.
SW. by S.	3 09 E.	2 15 W.
SW.	0 41 E.	4 30 W.
SW. by W.	2 15 W.	6 30 W.
W. SW.	5 01 W.	8 50 W.
W. by S.	8 03 W.	11 10 W.
W.	11 09 W.	13 15 W.
W. by N.	13 58 W.	14 15 W.
W. NW.	15 44 W.	15 30 W.
NW. by W.	16 27 W.	16 0 W.
NW.	17 22 W.	15 30 W.
NW. by N.	16 15 W.	14 15 W.
N. NW.	14 48 W.	11 50 W.
N. by W.	12 19 W.	8 30 W.

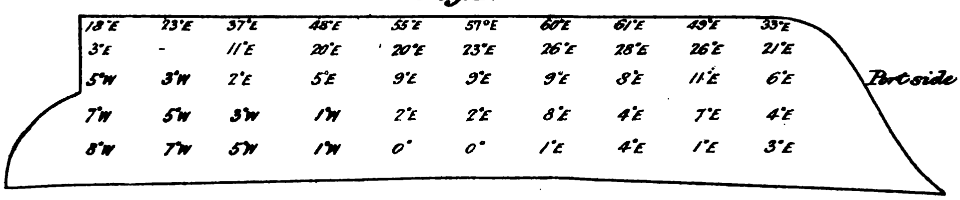


MAGNETIC COEFFICIENTS AND STARBOARD ANGLES.

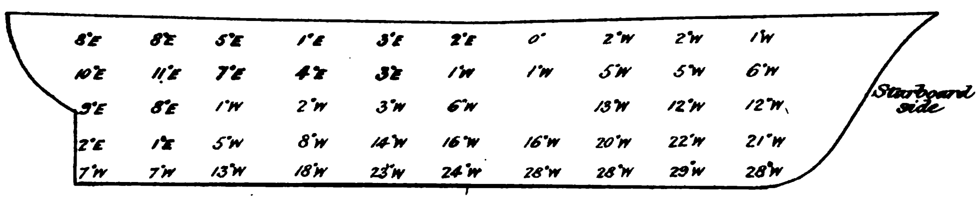
A.	— 0° 21′	— 0° 28′
B.	+ 11 06	+ 13 07
C.	— 7 25	— 3 24
D.	+ 4 0	+ 3 15
E.	— 0 18	— 0 14
Starboard angles......	328 20	346 13

Plate XVIII.

Fig. 1.

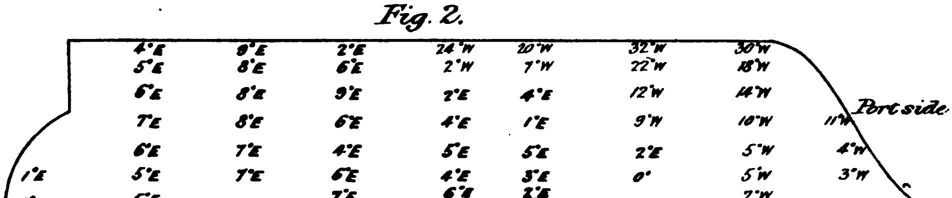


Survey while in Dry Dock at the Navy Yard, New York, June 1, 1883; Head, S. 33° W., Mag.
Survey made by Lieutenants Richard Wainwright and S. W. B. Diehl, U.S.N.

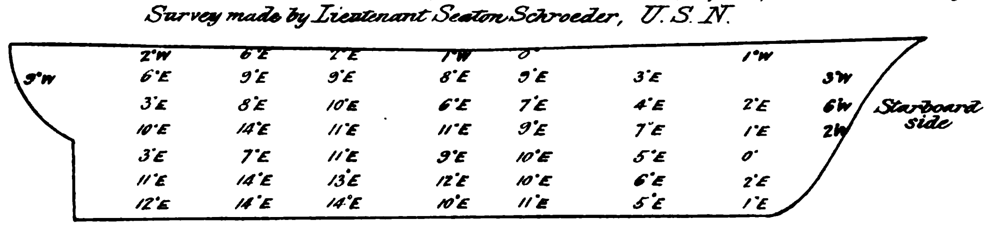


Magnetic Surveys of the U. S. Fish Commission Steamer Albatross (iron)

Fig. 2.



Survey while in Dry Dock at the Navy Yard, Norfolk, Va., July 18, 1884; Head, N. 73 W., Mag.
Survey made by Lieutenant Seaton Schroeder, U. S. N.



S. W. B. Diehl del.

CONCLUSION.

From all that precedes, it will readily be inferred that to place a compass where the magnetism of the ship will least effect it, is essential both to the safety of the vessel and to the good behavior of the instrument itself.

No compass, however excellent its workmanship, will perform with sensibility, steadiness, and accuracy, if set in the midst of vitiating influences that practically counteract the skill of the maker—skill which originally endowed it with the requisite qualities in a high degree.

Compensation of large deviations by means of magnets is at best but a remedy for an ailment; better not sow the seeds of the disease.

The immediate surroundings, so far as practicable, should be of non-magnetic metal; if the stanchions, railings, hatch-coamings, and all similar fittings in the vicinity of the compass were of brass or copper, then much of the strain upon the compass would be relieved, and it would mainly have to struggle with its inevitable antagonist—the magnetism of the hull; and possibly the force of this may be found so weak in some spot as not to necessitate compensation.